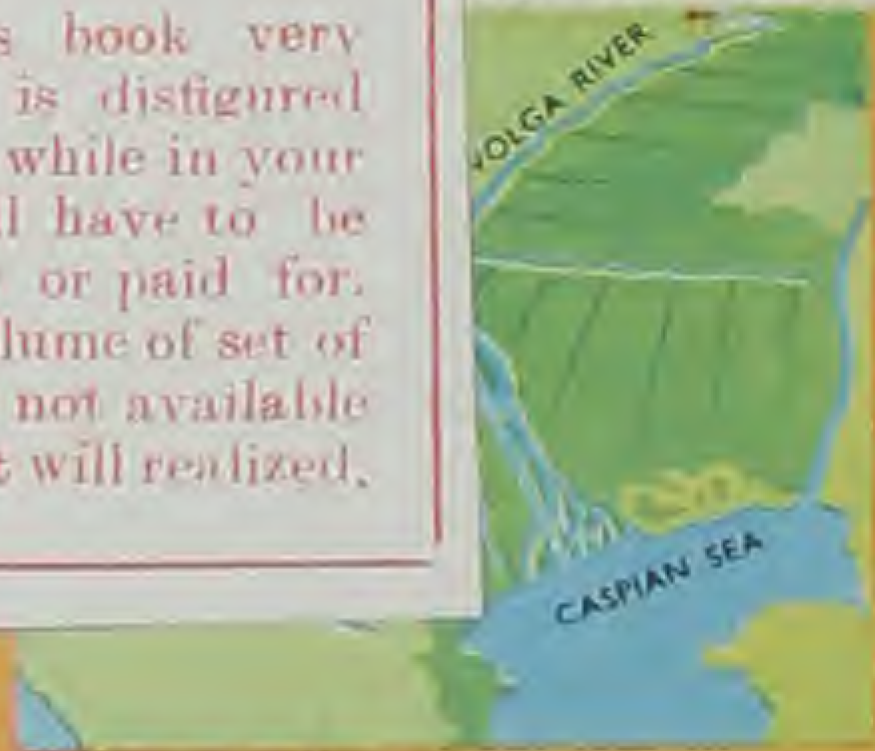
...YS OF INCREASING THE


In North and South America the yield of food per acre has been greatly increased by the use of fertiliser.

In the Amazon basin tree roots protect the soil against heavy rainfall. Ordinary crops produce erosion. What is needed is a food bearing tree.

A scheme which may sound fantastic is that cheap atomic power might enable seawater to be pumped over the Sahara Desert to turn it into a salt marsh on which sheep could graze.

New breeds of cattle that can stand heat are being developed. They could prosper in the hot grasslands of Africa.



NEW IRRIGATION CANAL
The joining of the Volga and Don Rivers by a new canal has meant increased irrigation for surrounding steppes. To protect the new crops from wind sweeping across the flat land, wide belts of trees have been grown.

The U.S.S.R. is endeavouring to extend the cultivated area northwards by breeding shorter season cereals.

INCREASED IRRIGATION
Barrages are being built to hold back the Nile flood waters. Being raised in level as well as retained the water is available for irrigating much l...

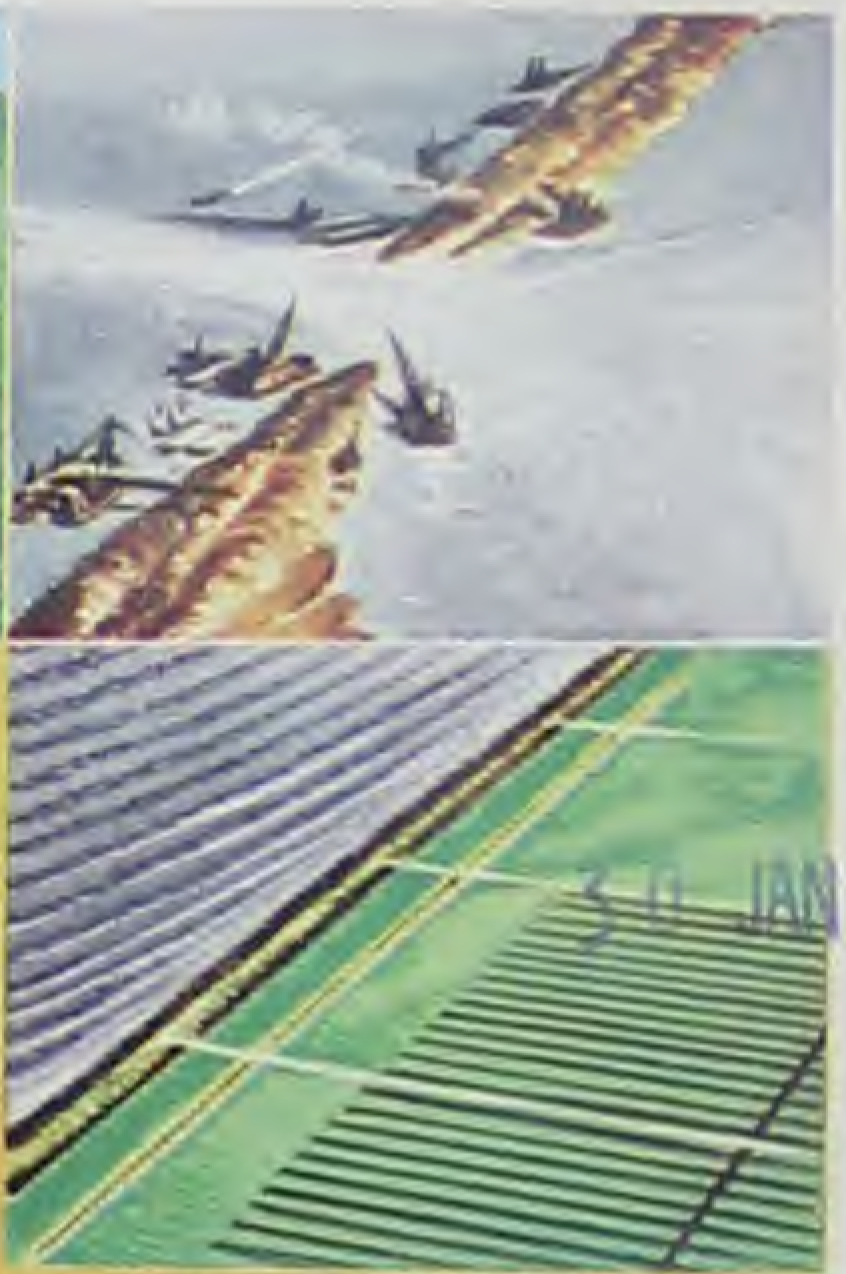
THE CONSUMPTION OF FISH
...fish will not keep when ...sea, so village fish ponds ...d. Eggs are hatched in ...hen full grown the villagers ...fresh fish.

THE WORLD'S FOOD GROWING AREAS

The water is raised from the Volga to a summit level by a system of locks, it then passes down through more locks until it reaches the Don.

A stone and willow mattress being lowered into position as a foundation for the dam.

Damming the Mediterranean at Gibraltar, and lowering its level by pumping would expose a coastal fringe which might be suitable for cultivation.



Top picture shows the closing of the final gap in the dam. Below: the reclaimed land is being drained. Note the height of the water beyond the dam.

In parts of Australia and New Zealand greater use of fertiliser has increased the yield per acre.

Some remote possibilities are here shown alongside actual schemes that have already been adopted to increase the amount of food grown in the world.

RECLAMATION OF THE ZUIDER ZEE

The Dutch have already reclaimed much of the Zuider Zee. A dam from Weiringen to Friesland made it a non-tidal lake. Other dams cut off corners of the "lake". Water was then pumped out from these "polders" into the "lake" and then into the sea. Special grass is grown on the salt soil to prepare it for crops.

REVERSING THE FLOW OF A RIVER

The area north of Australia's Snowy Mountains is short of water. The head-waters of a river, the Snowy, that rises in the range but flows south, where there is enough rainfall, has by a system of dams and many miles of tunnels bored through the mountains, been made to flow into the dry area and increase the water supply used to irrigate it.

PROVIDING TRACE ELEMENTS

Fertile soil must contain minute traces of all the elements. In Australia miles of land was barren for the lack of Zinc, Copper and Cobalt. These were sprayed on; the area is now used for stock raising.

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Introduction

The Editors and Publishers of *The Pictorial Encyclopædia of Scientific Knowledge* are proud to present to their readers the complicated subject of Science in a new unique encyclopædic form. This is, they believe, the first book to attempt to explain the whole of elementary scientific knowledge purely in terms of pictures. The illustrations have been so designed that a single picture is often sufficient to make a scientific law clear and believable, and so interestingly presented that readers of all ages—even those who have never been interested in science—will find themselves asking questions and then discovering their own answers !

The many hundreds of brilliant illustrations will build up for each reader a full and confident understanding of the basic sciences, and at the same time give an intensely interesting account of the scientific interpretation of the universe around us. The Editors have given the evidence in simple form in their picture articles, so the truths of the laws of science are reached as the reader's own conclusions. Instead of being baffling, as normally presented, they become clear and convincing.

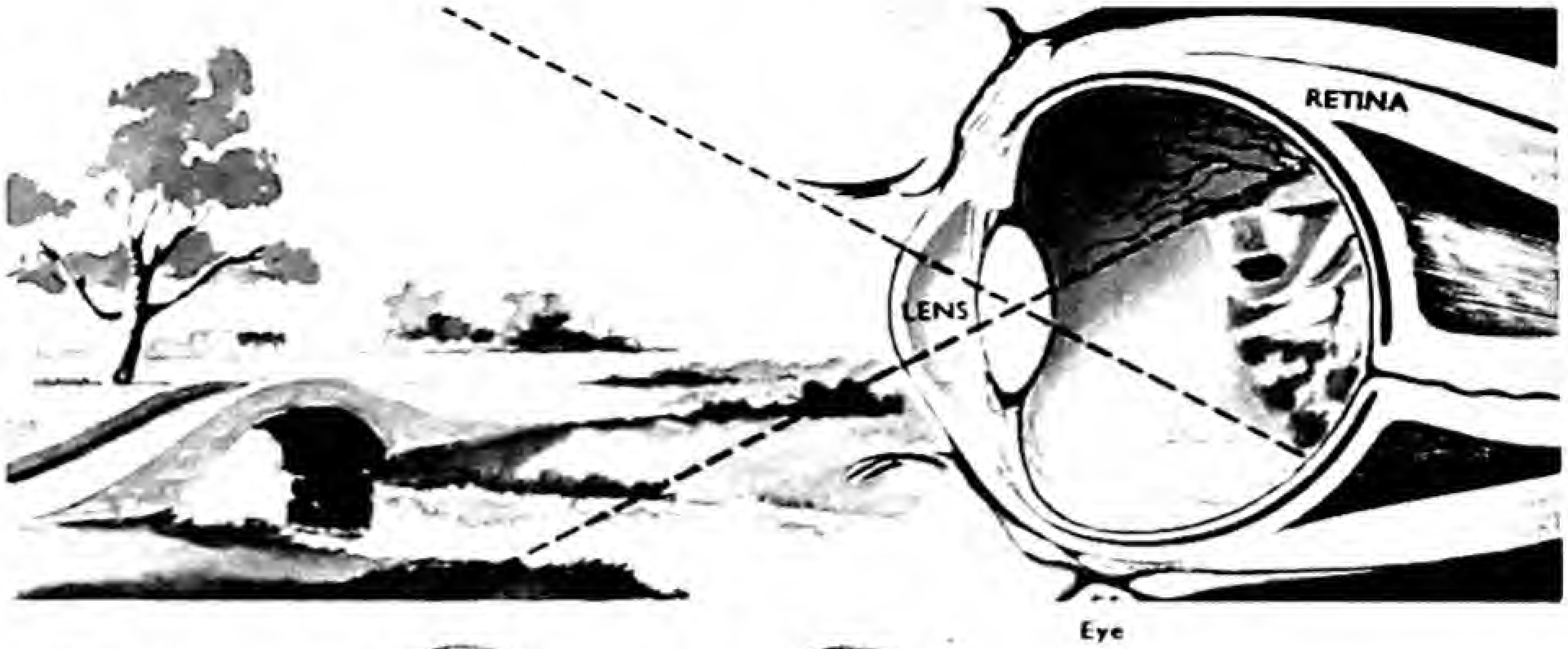
The sections are not set out in any conventional order of the separate sciences, for Science is the whole study of observed facts, all the " sciences " being part of Science as a whole, each overlapping many of the others. So the whole is linked by a comprehensive index and a series of reference sections which are an exhaustively cross-referenced list of the interlocking aspects of each science.

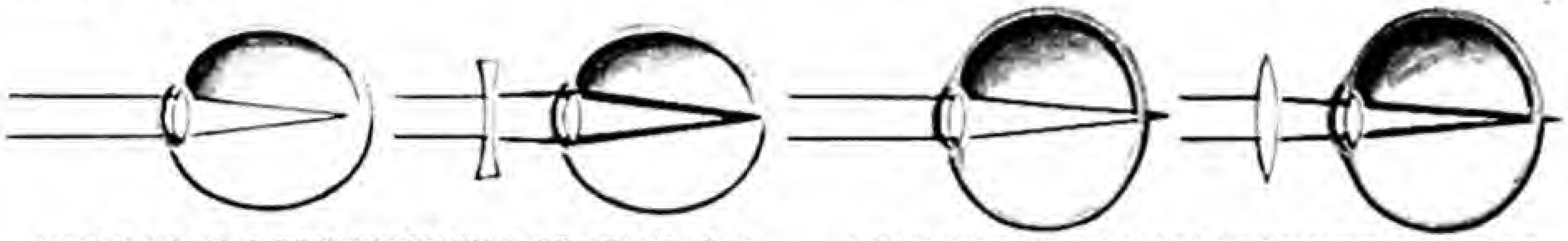
The Editors believe that in making these pictorial surveys of at least the elementary part of the immense present sum of scientific knowledge they will have aroused in their readers an awareness of what science means, and have given them the great satisfaction of taking part in the study of the universe.

Contents

THE MICROSCOPIC WORLD

The eye is like a camera in which the film is a curved sheet of nerve tissue called the retina. The lens casts on the retina an upside down image of what the eye is looking at, but the brain "reads" this the right way up.

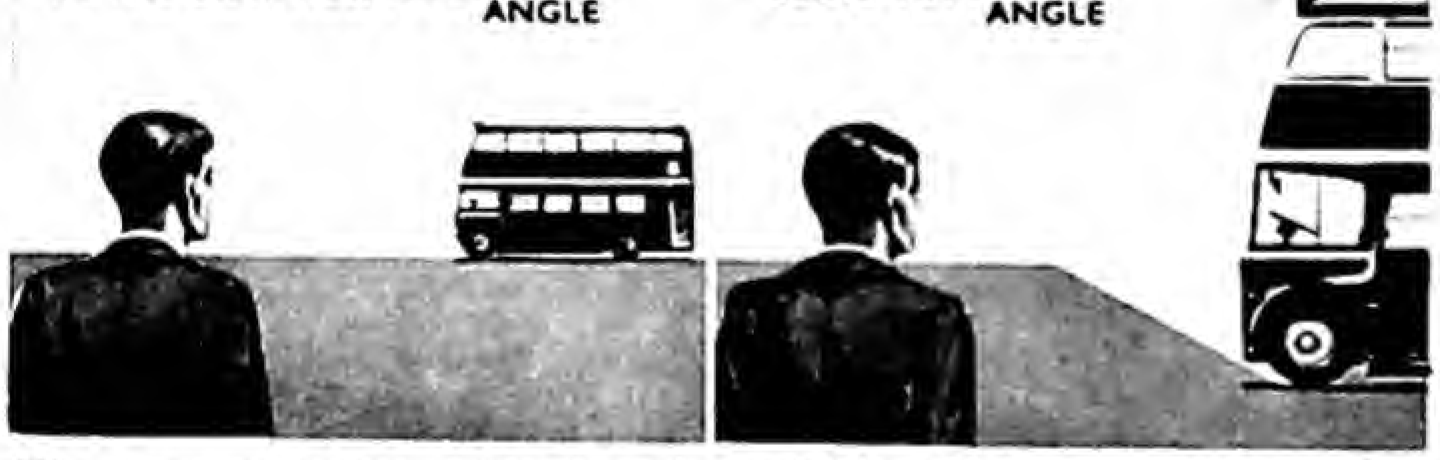




SHORT SIGHT IS CORRECTED BY A CONCAVE LENS. LONG SIGHT IS CORRECTED BY A CONVEX LENS.

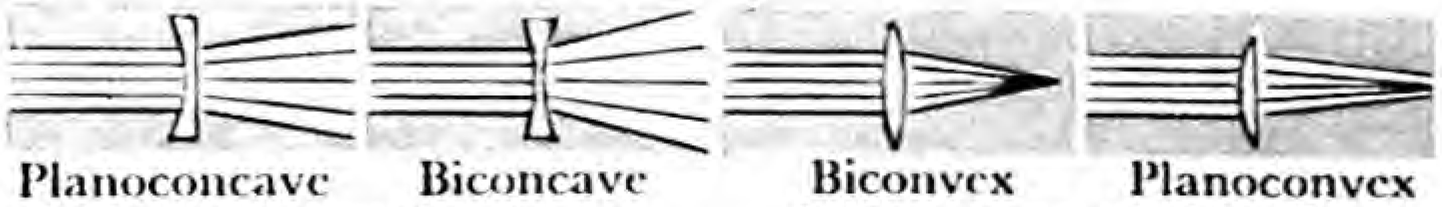
People who have short sight usually have an eyeball which is too long for the image to be focused far enough back to fall on the retina. A concave spectacle lens expands the light beam and helps the eye's lens to focus a distant object on the retina. In long sight the image would be formed behind the retina. A convex lens corrects this by converging the beam of light so that the eye lens can now focus it on to the retina. The beam of light is shown parallel as it comes from a distant object.

IN THE DISTANCE, A NARROW ANGLE CLOSE TO, A WIDE ANGLE



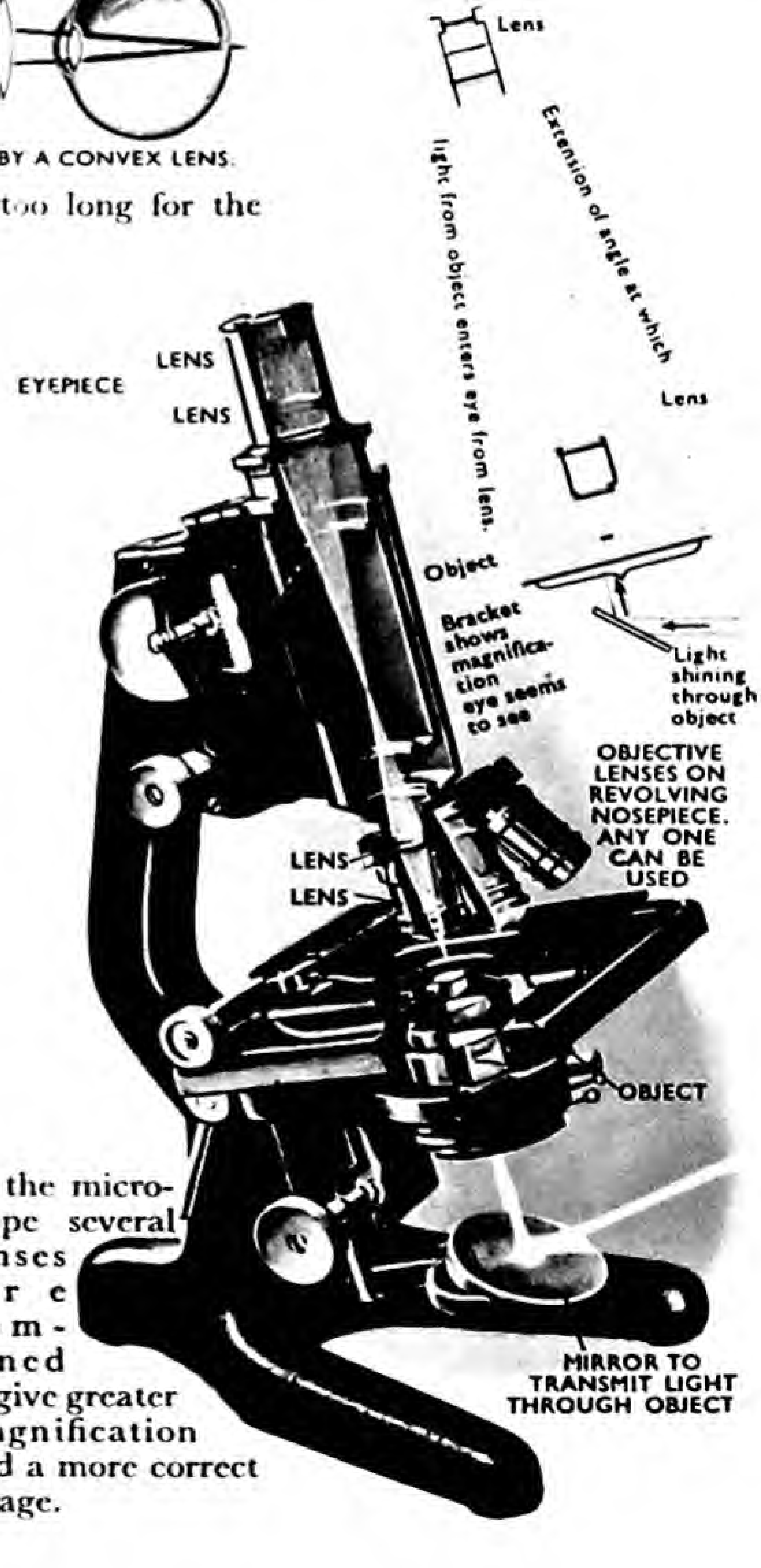
The eye measures size by the width of the angle from the edges of the object seen. A convex lens bends light rays from an object so they enter the eye at a wide angle (as if they were nearer and bigger). So convex lenses are used to

magnify small objects. Without a lens, light from object *a*, *b*, enters eye at small angle shown. But with a lens in use the angle is made larger, and the eye reads this as if the object was really larger.

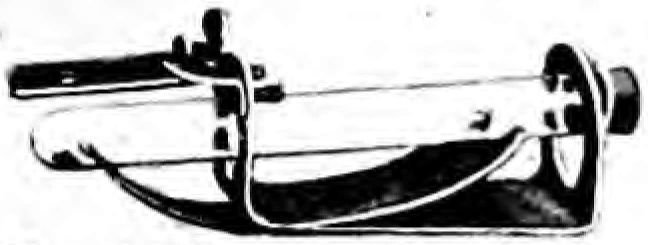


Planoconcave Biconcave
These are diverging lenses

Biconvex Planoconvex
These are converging lenses

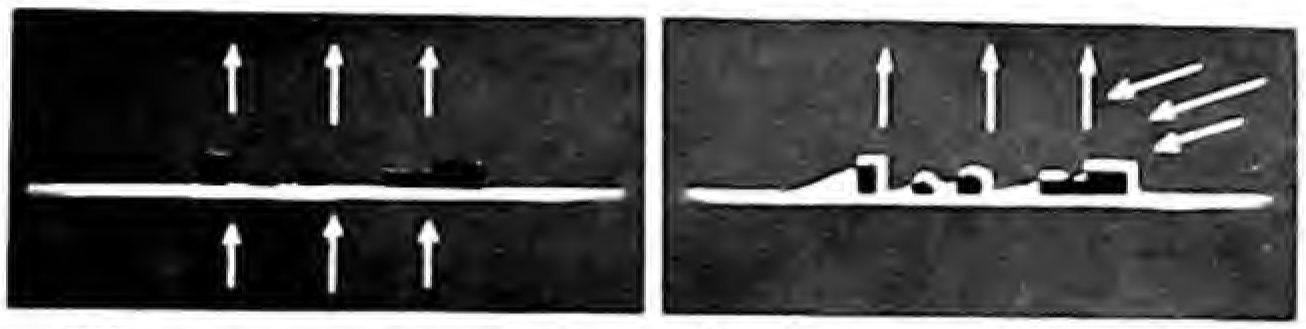


In the microscope several lenses are combined to give greater magnification and a more correct image.

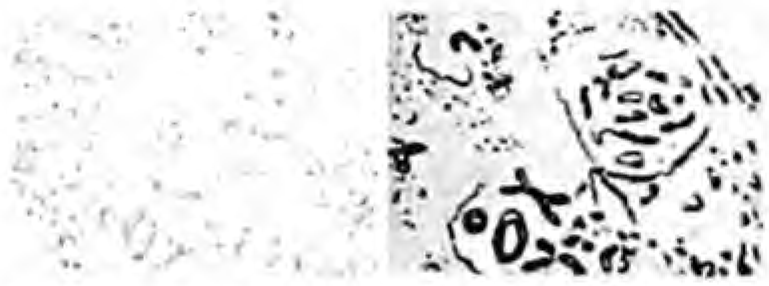


The single lens microscope (*above*) of Antonj van Leeuwenhoek (1632–1723) was like a pocket magnifier; the distance of his eye from the lens holder focused it.

Robert Hooke (1635–1703) made a compound microscope (*right*) which enabled him to see the cells in the bark of a tree.

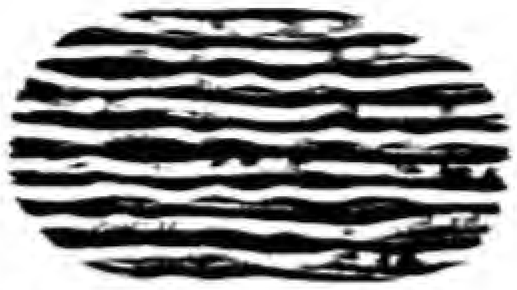


There are two ways of using a microscope. One is by transmitted light (*left*), which reveals the transparent object in tones of varying brightness. The other (*right*) is by the use of light from the side reflected by the object. Shadows will be cast by the higher parts, which will themselves appear light.



Living chromosomes (*left*); fixed and stained (*right*).

Dirt collected by a gramophone needle.



The sound waves on a gramophone record.

The hairs on a stinging nettle.

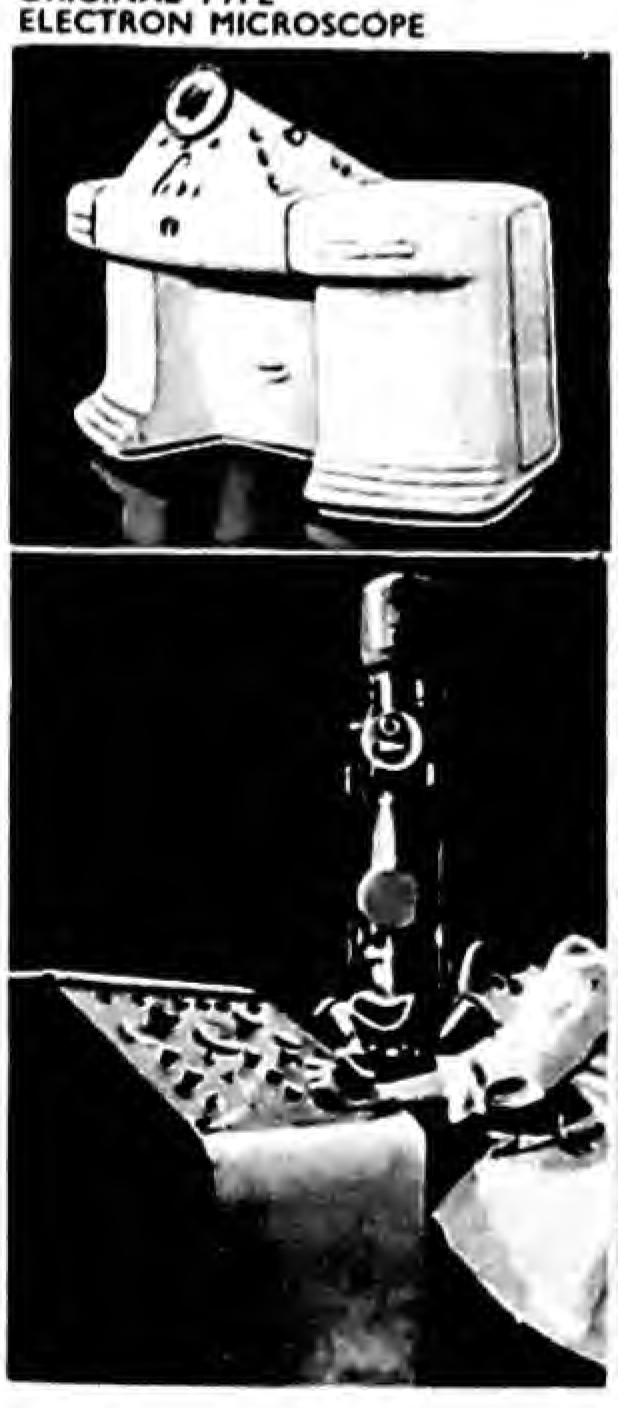
Fixing and Staining

Small creatures are often examined alive under a microscope. But for closer study it is better to kill them with a fixing liquid specially chosen to prevent shrinkage. Transparent things like bacteria are stained with dye to show up their details.

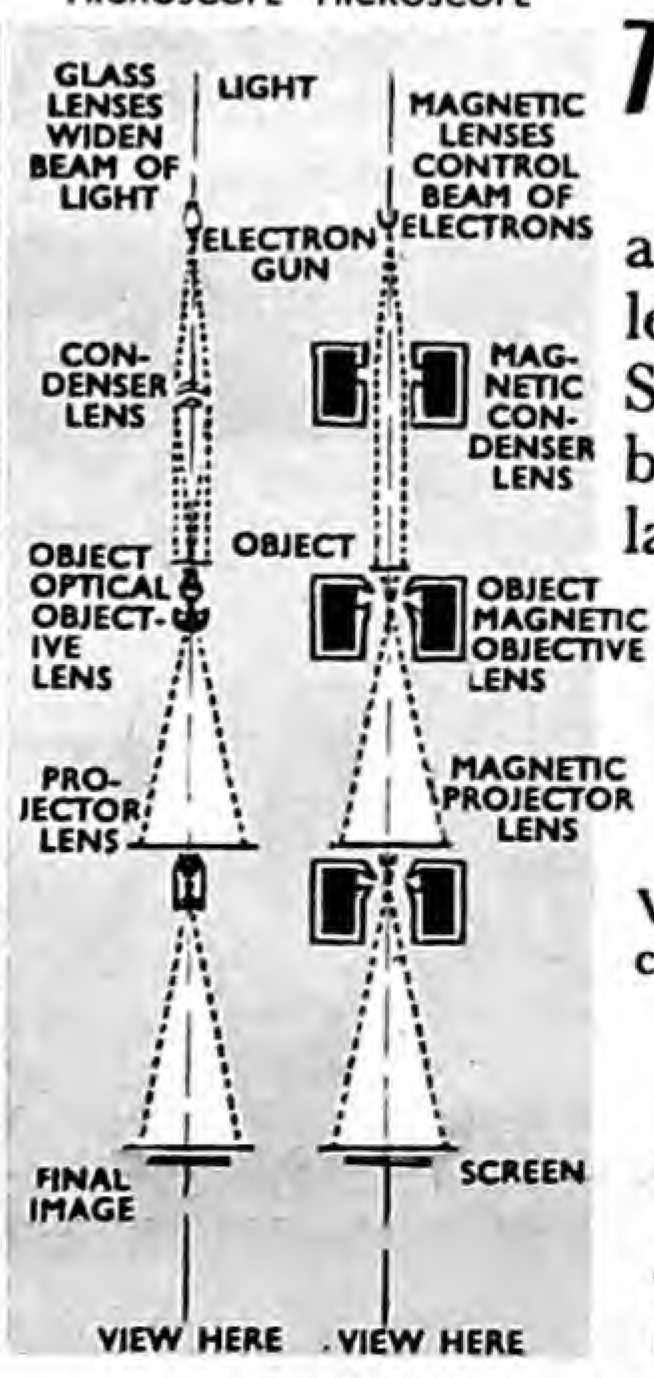
A letter "a" from this page showing a gravure screen.

The change in the structure of the starch grains when a potato is boiled. The raw potato is on the left, the cooked on the right. When boiled the grains burst. This makes the potato easier to eat and digest.

DESK TYPE AND (BOTTOM) ORIGINAL TYPE ELECTRON MICROSCOPE



ORDINARY MICROSCOPE — ELECTRON MICROSCOPE



The Electron Microscope

Things too small to disturb ordinary light, are placed in an electron beam, the wave length of which is shorter than that of light. So the object can disturb it and when the beam falls on a fluorescent screen an enlarged image will be seen.

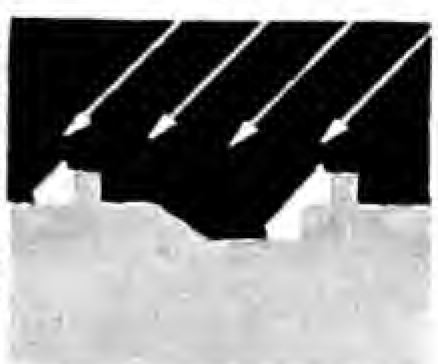
Virus particles on chick red cell.

Crystals in zinc oxide smoke.

A common type of bacterium.

The fibrous structure in the skin.

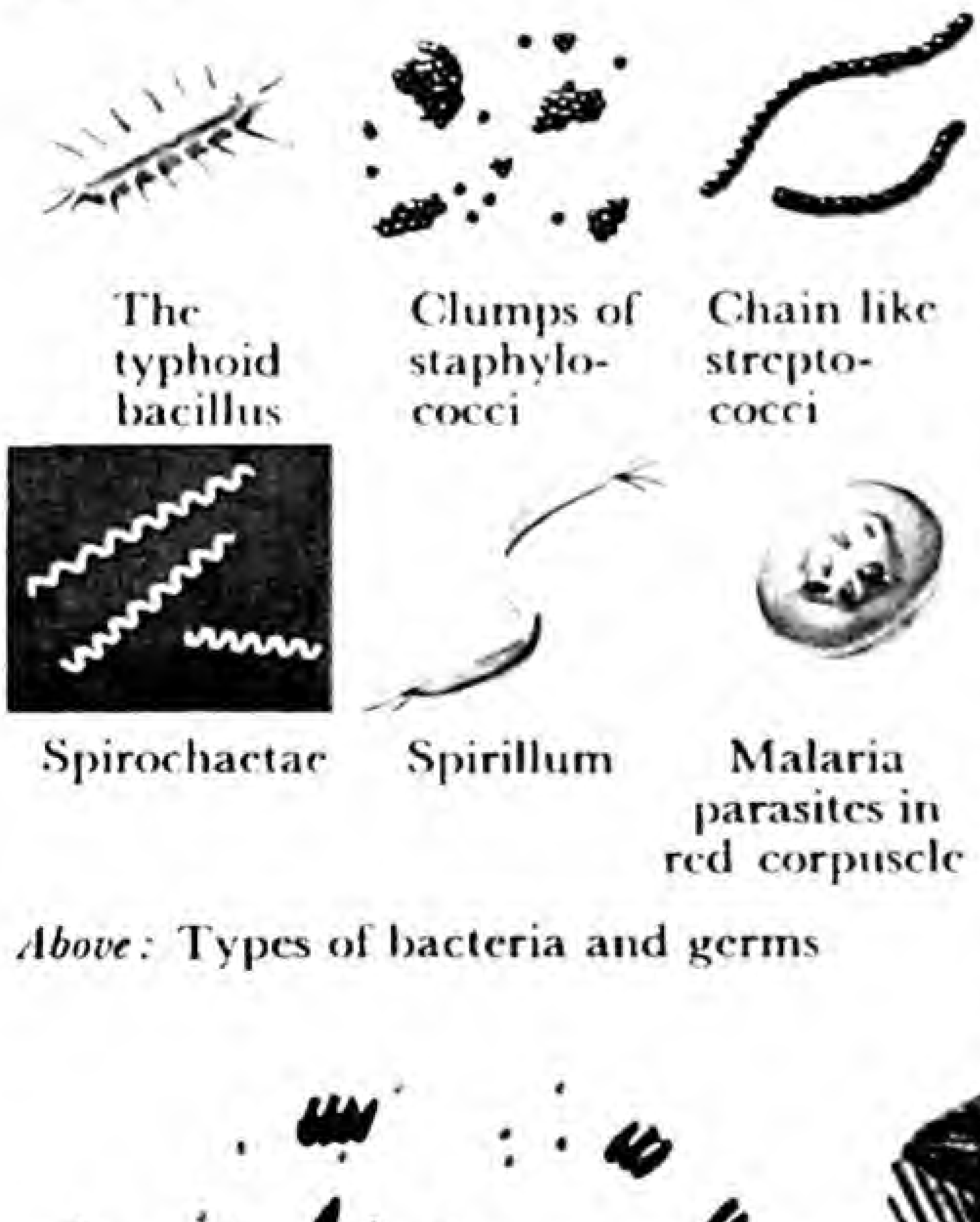
These objects (*right*) are shadow cast, showing them up, by directing gold particles onto them.



The reason why very small objects are not seen in a beam of light is that they fail to create a disturbance in the wavelength pattern of the beam. It is rather like the passing of sea waves through a row of posts. The longer wavelengths go through the gaps between the posts and receive so little disturbance that it has vanished before the crest of the next wave. The waves therefore continue unchanged. The wavecrests of shorter wavelengths passing between the same posts are disturbed in such a way that they receive a lasting pattern. It is as if the wave system had bands of shadow imposed on it. Electron beams have a shorter wavelength than light beams. As in the model this means that they receive a pattern from passing through very small objects where light would not receive a pattern. Because of this the magnetic lenses that are used to focus electron beams can form an image of the tiny object. Of course the eye cannot pick up an electron beam so the beam is turned into light and shade on a television screen.

Bacteria and Germs

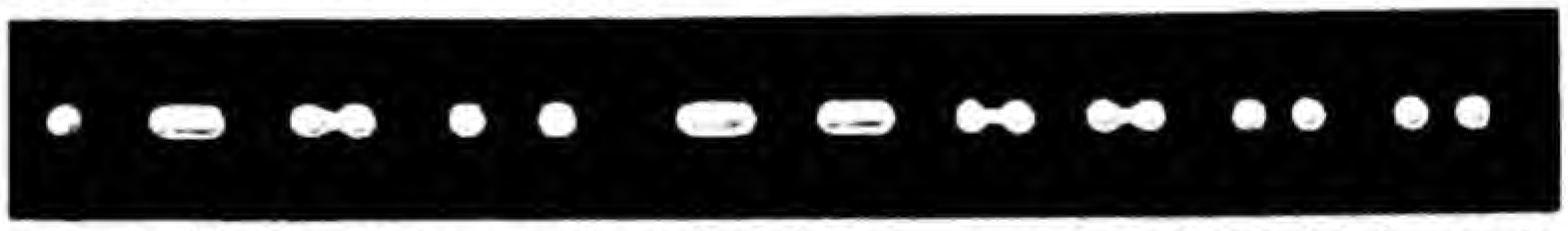
Bacteria are tiny organisms of varying shapes, so small that they can be seen only under a microscope. A small number are harmful, causing diseases such as typhoid or pneumonia ; others are beneficial and are used in cheese or butter making. The most important bacteria are those that bring about the decay of dead animals.



The typhoid bacillus — Clumps of staphylococci — Chain like streptococci

Spirochaetae — Spirillum — Malaria parasites in red corpuscle

Above: Types of bacteria and germs



In suitable conditions (when they have warmth and water) bacteria divide in two every 20 minutes

Blood contains white corpuscles which wrap themselves round harmful bacteria and digest them.

Frozen food does not decay because bacteria are unable to multiply unless they have warmth.

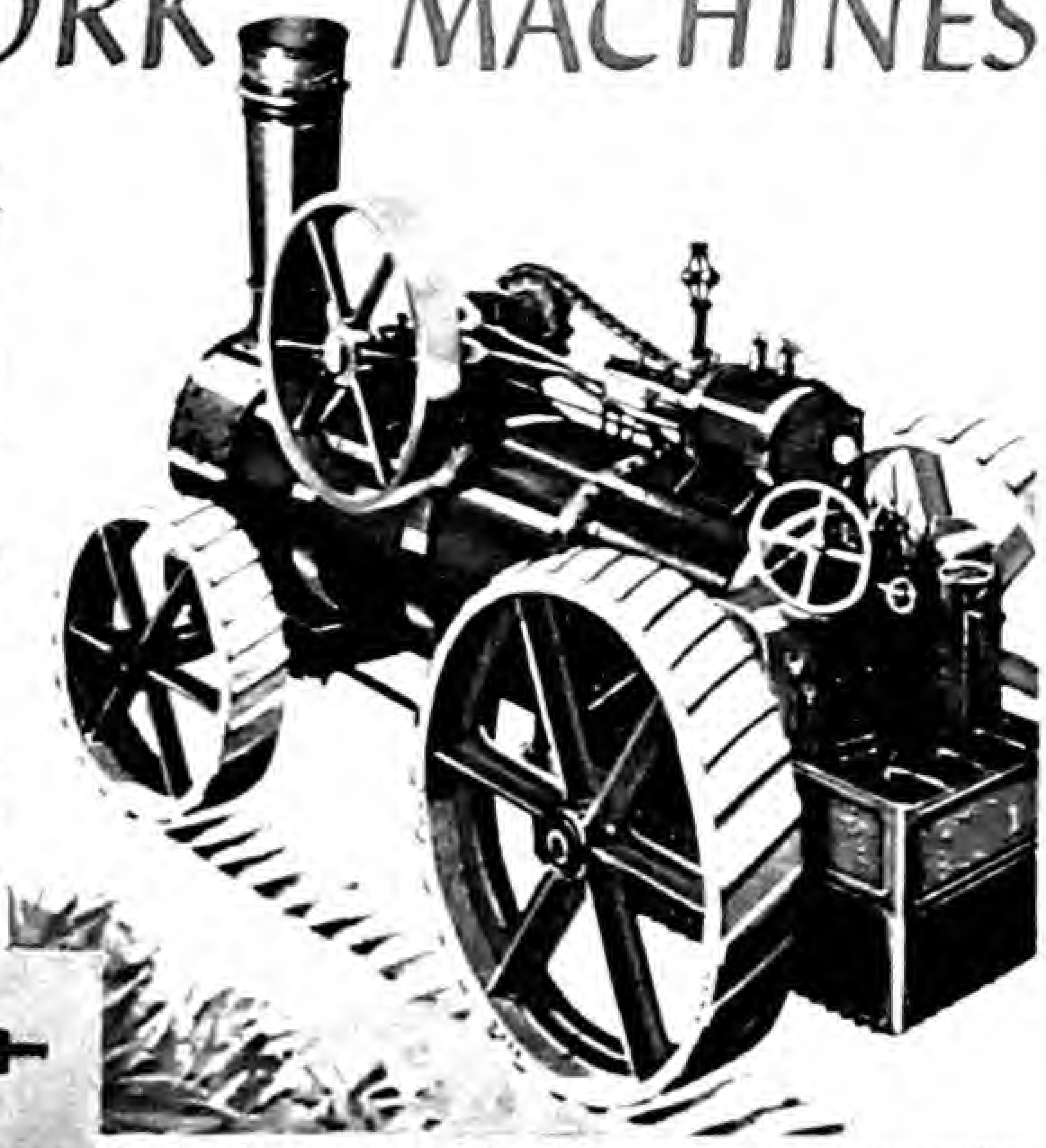
Some bacteria are used in cheese making. They clot the milk and give distinctive flavours.

MAKING HEAT WORK MACHINES

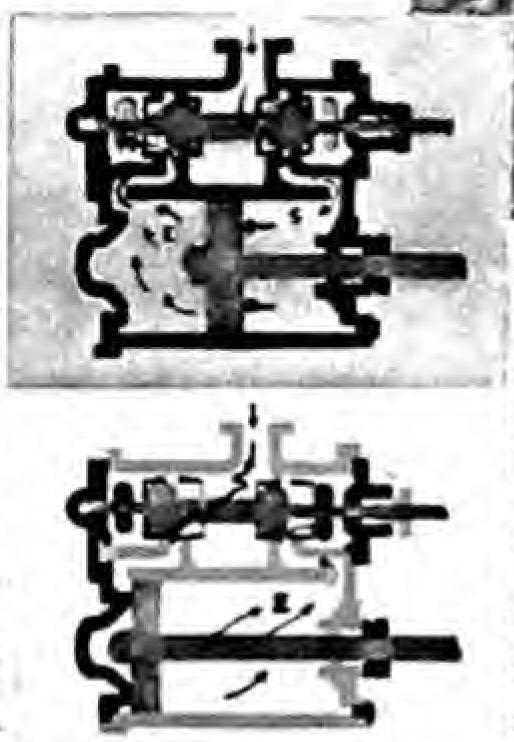
Until it was realised that gases expand when heated (that is, that the same weight of gas when heated takes up more room) neither the steam engine nor the internal combustion engine could be invented. It also happens that some liquids when heated enough turn into gases.

Steam is a gas and the more it is heated the more it expands. Because of this, water can be used to work the steam engine.

The first inventors of heat engines, men like Newcomen and Watt, heated water in a boiler strong enough to prevent the steam expanding naturally. The steam was then released into a steam-tight tube (the cylinder) which had one end free to slide along inside it (the piston). As the steam expanded, it pushed the piston outward and so, by the connecting rod, turned a wheel. Before the piston could be returned to its starting position the expanded steam had to be released through a valve.



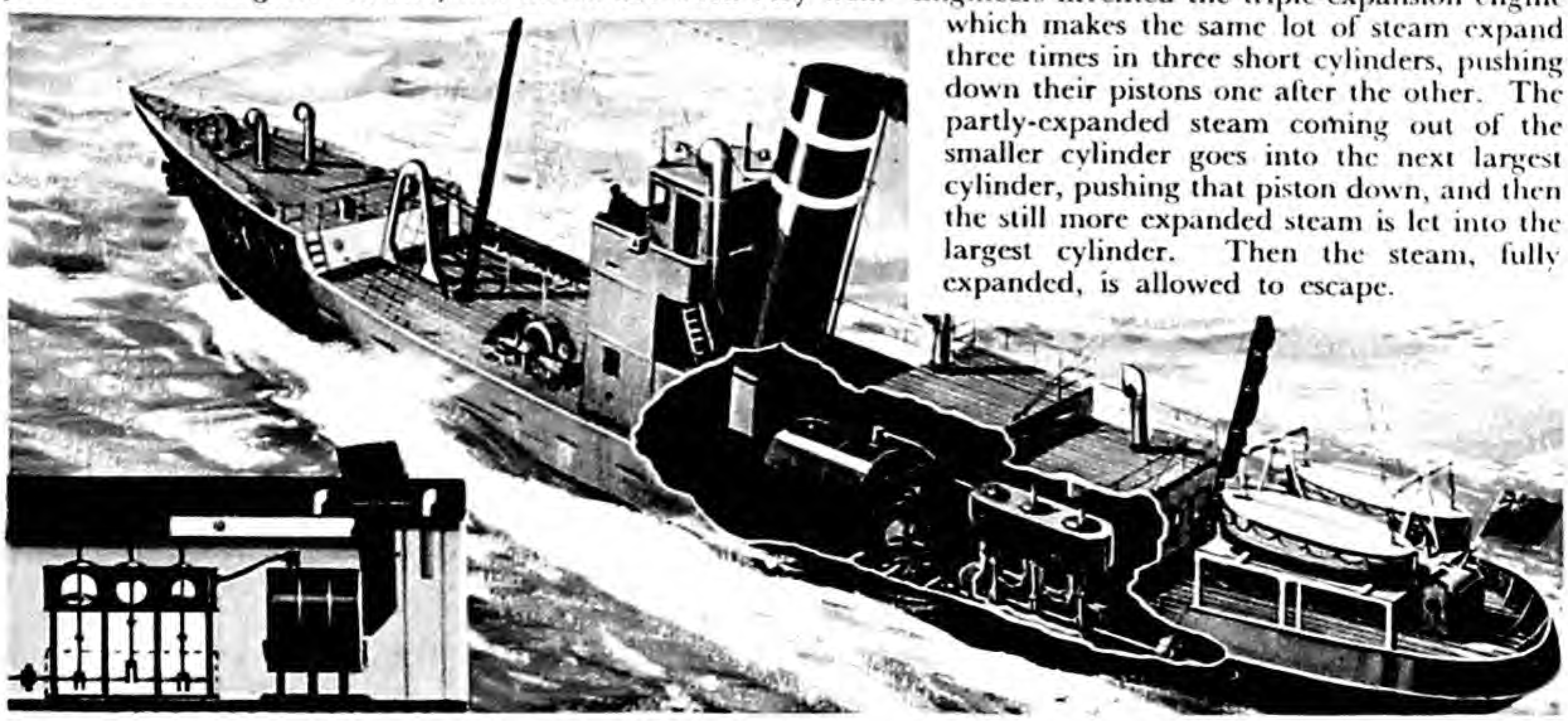
A simple steam engine powers a traction engine. Steam under pressure from the boiler enters the cylinder and by expanding pushes the piston forward. The piston could not do this if it had to compress the first lot of steam again, so a lever pulled by the crankshaft opens a valve in the side of the cylinder and releases the expanded steam. As the piston reaches its starting point again, this valve is closed. More steam now enters the *other* end of the cylinder and pushes the piston the other way.

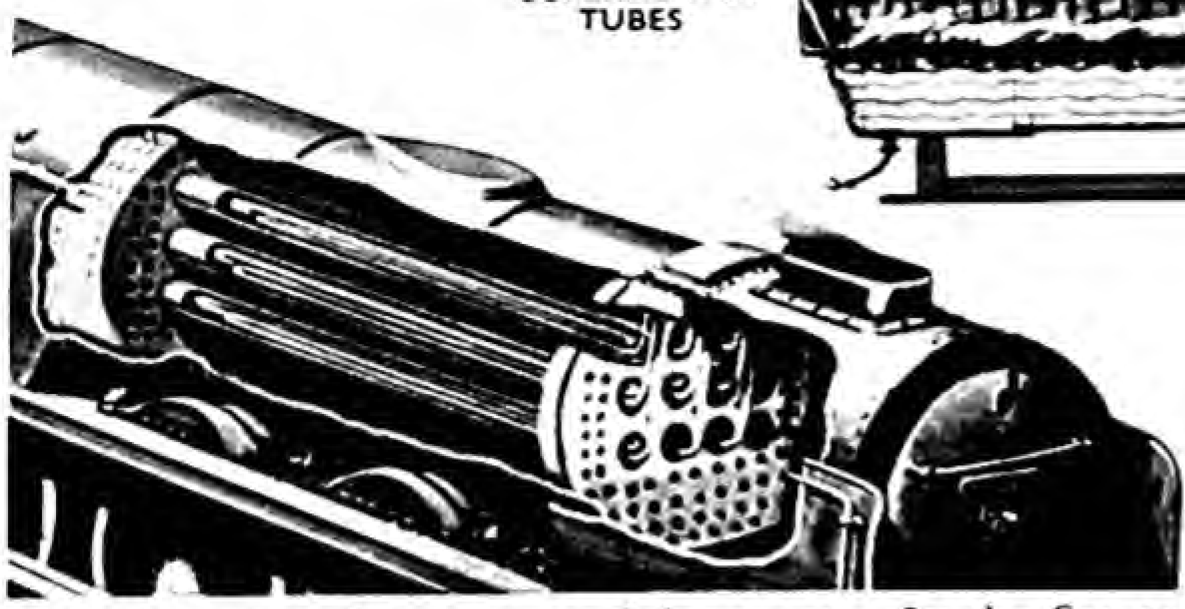


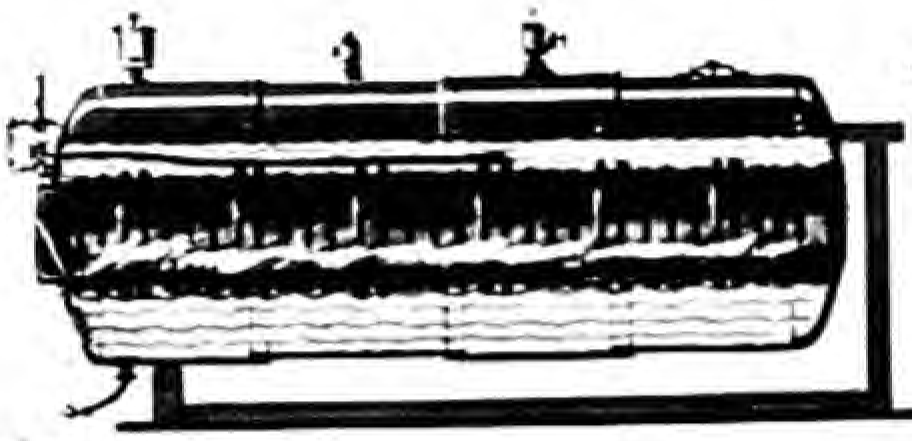
S – Steam under pressure.

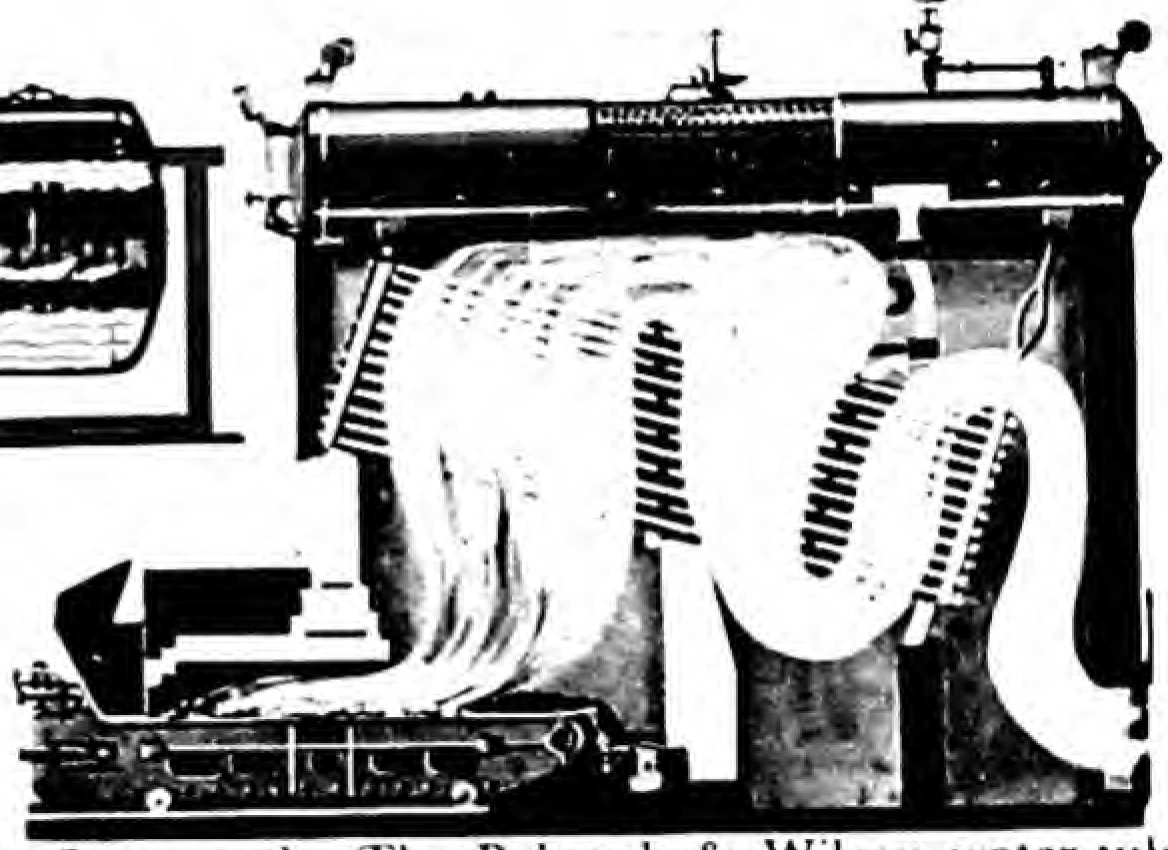
E – Exhaust (expanded steam).

A very long cylinder to let the steam expand a long way would at first sight seem to be the way to make a more powerful steam engine. In fact, this would not work very well. Engineers invented the triple-expansion engine which makes the same lot of steam expand three times in three short cylinders, pushing down their pistons one after the other. The partly-expanded steam coming out of the smaller cylinder goes into the next largest cylinder, pushing that piston down, and then the still more expanded steam is let into the largest cylinder. Then the steam, fully expanded, is allowed to escape.





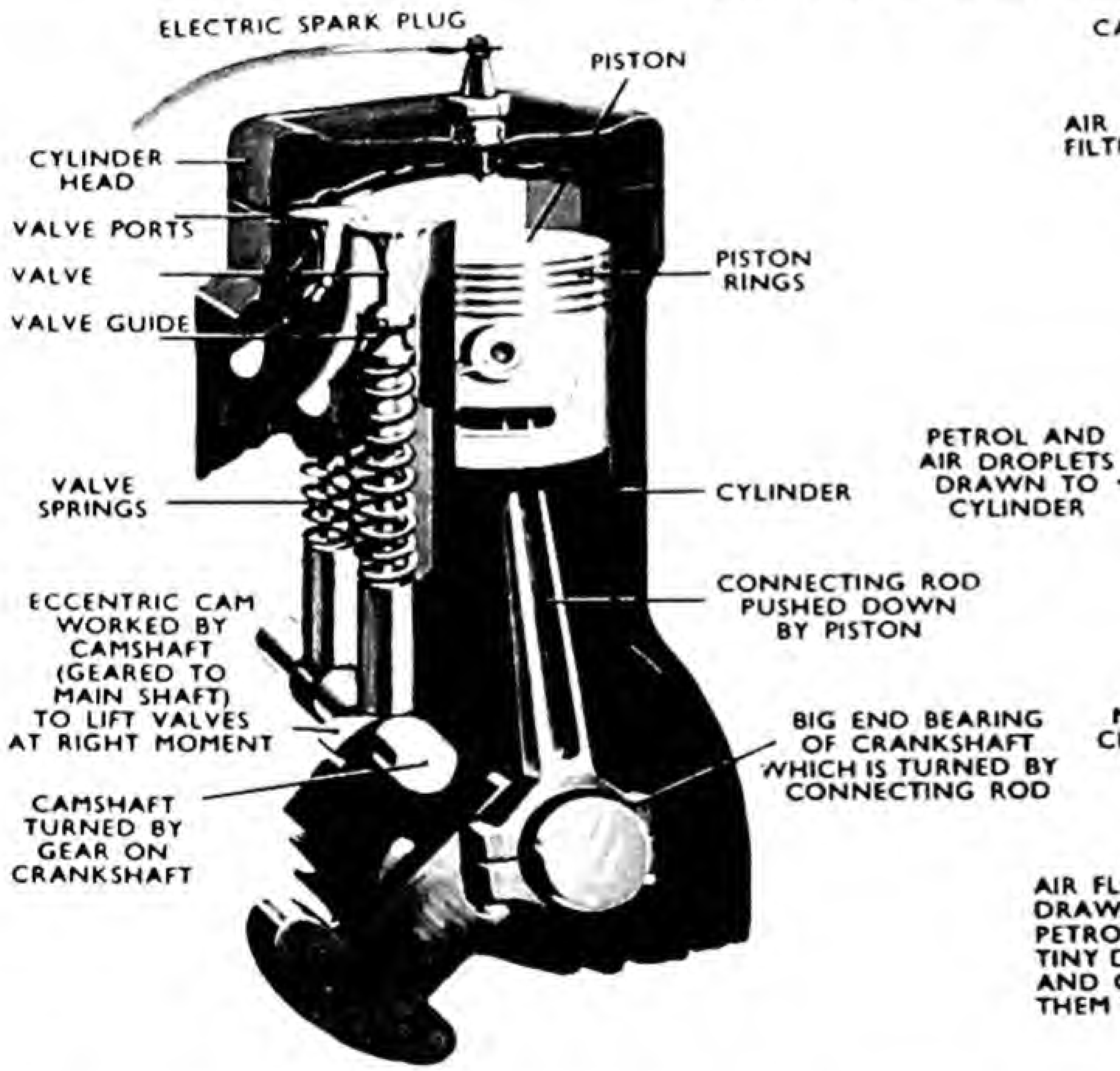


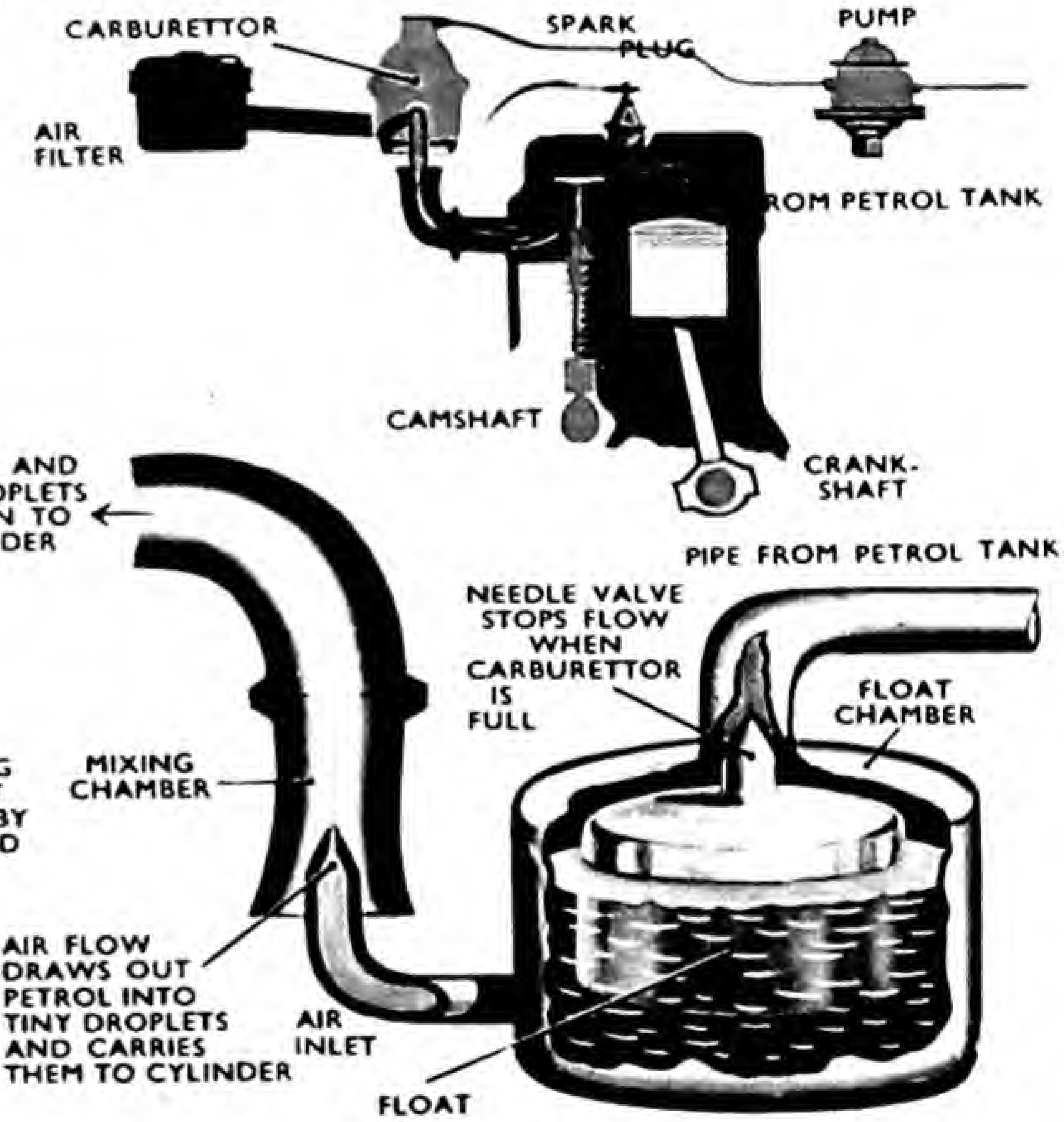


Superheater tubes are used in most steam railway engines. They lead the steam back through the path of the flames so that it is twice heated and able to expand more.

In the fire-tube boiler, the flames and hot gases from the furnace are led through flues that run through the middle of the boiler shell, so the water takes the greatest possible amount of heat from the gases.

The Babcock & Wilcox water-tube boiler has another way of putting a greater surface of water in contact with the furnace heat. The water passes right through the flames in its tubes.





This is one of the simplest and most easily maintained machines possible. And the steam engine is still one of the main types of power machines.

Almost any gas cooled to its liquid form could, in theory, be put into the boiler of a steam engine and made to work like steam. In fact, none of them would be so efficient, and most of them would cause special difficulties.

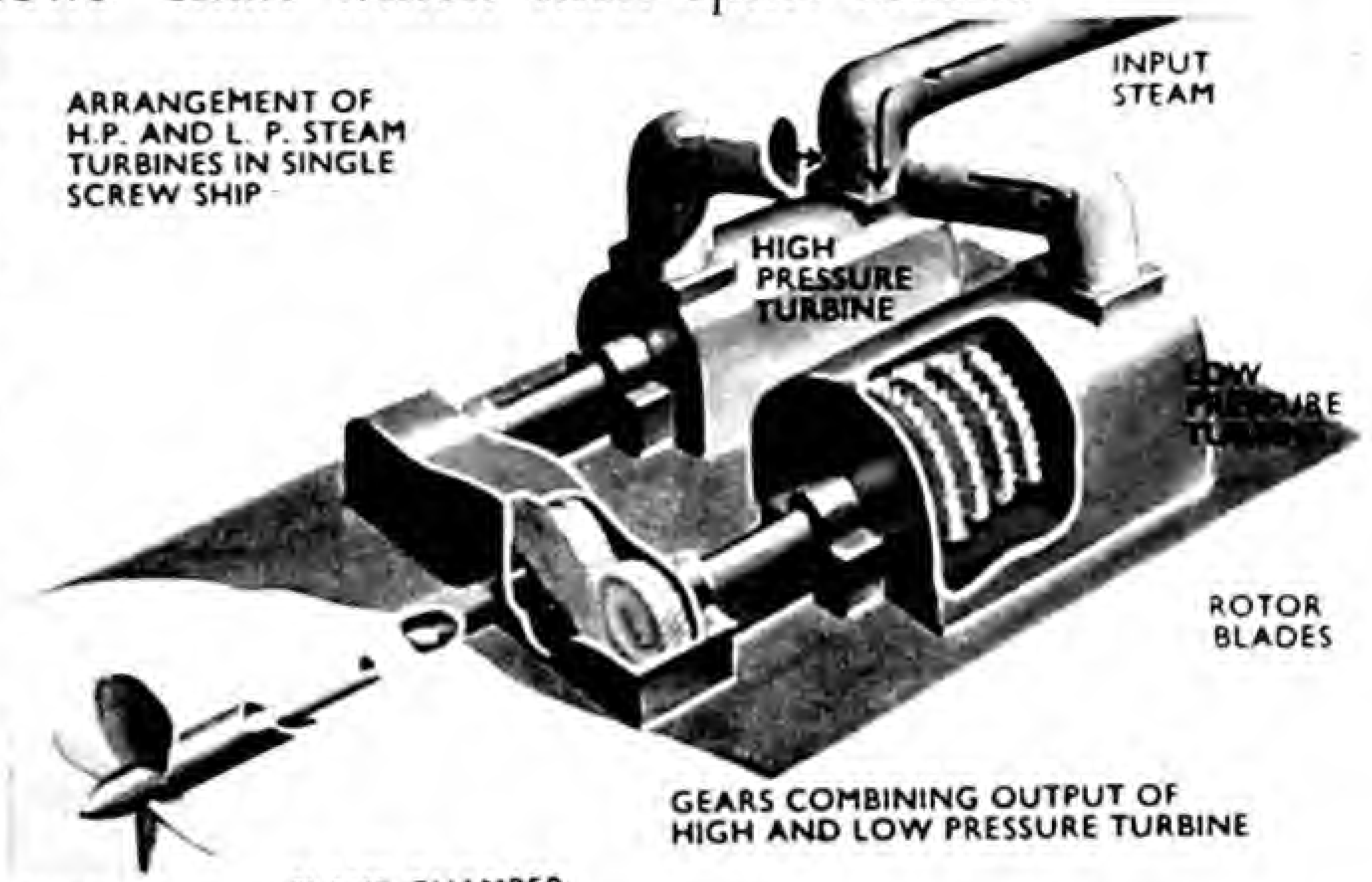
Engineers at the end of the 19th century invented an engine which does away with the need for a furnace. This is the internal combustion engine, called that because the burning (combustion) is done inside the cylinder, instead of outside it under the boiler as in the steam engine.

A carburettor mixes droplets of petrol

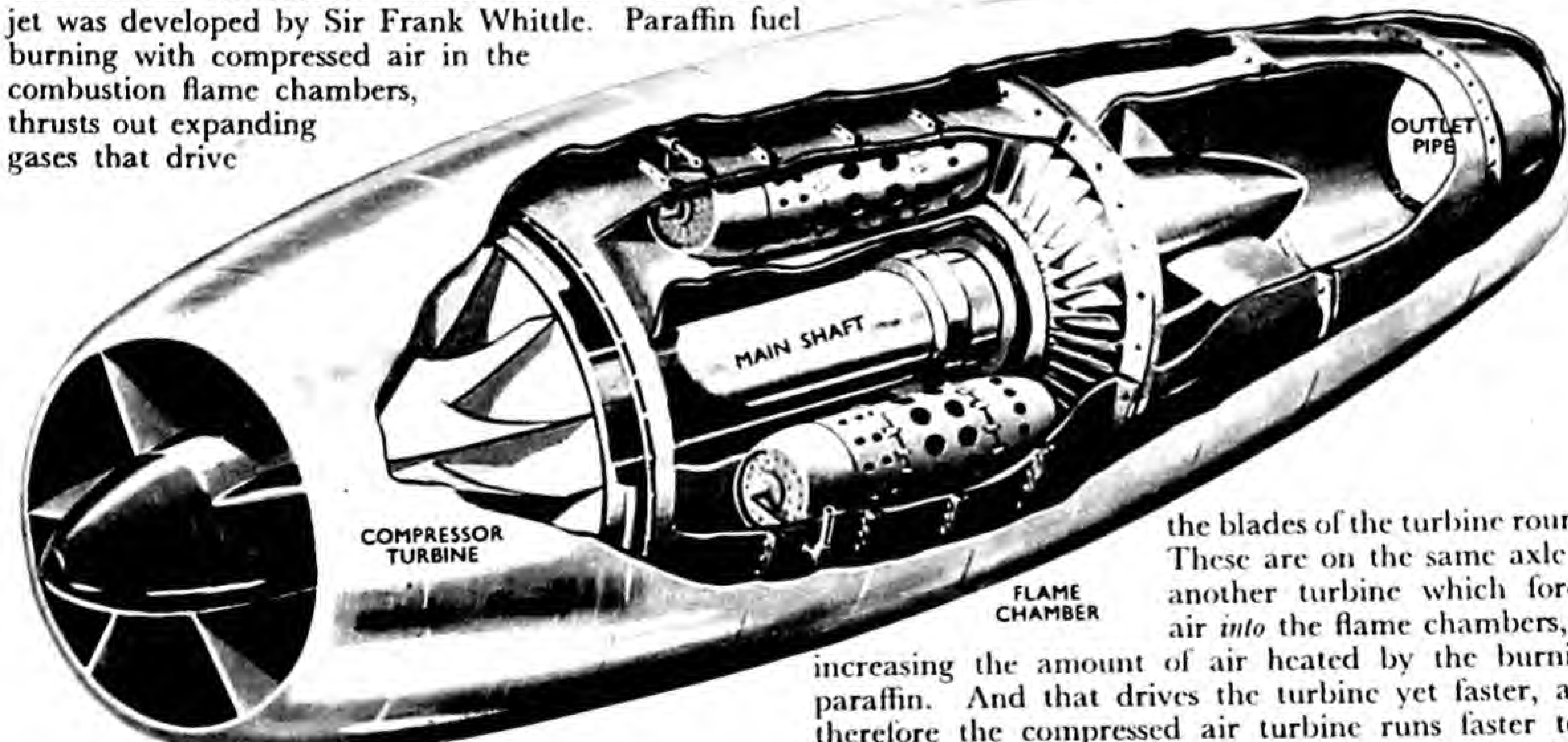
with air. The mixture goes into the cylinder and is set on fire by means of an electric spark. The burning of the petrol in the air *inside* the cylinder produces other gases which, being heated by the explosion, expand and push the piston.

One down stroke in the four-stroke petrol engine—the most usual type of car engine—is a driving stroke. Then follows an exhaust stroke pushing out the burned gases. The next down stroke draws fresh mixture into the cylinder. A second up stroke compresses it in readiness for the next driving stroke.

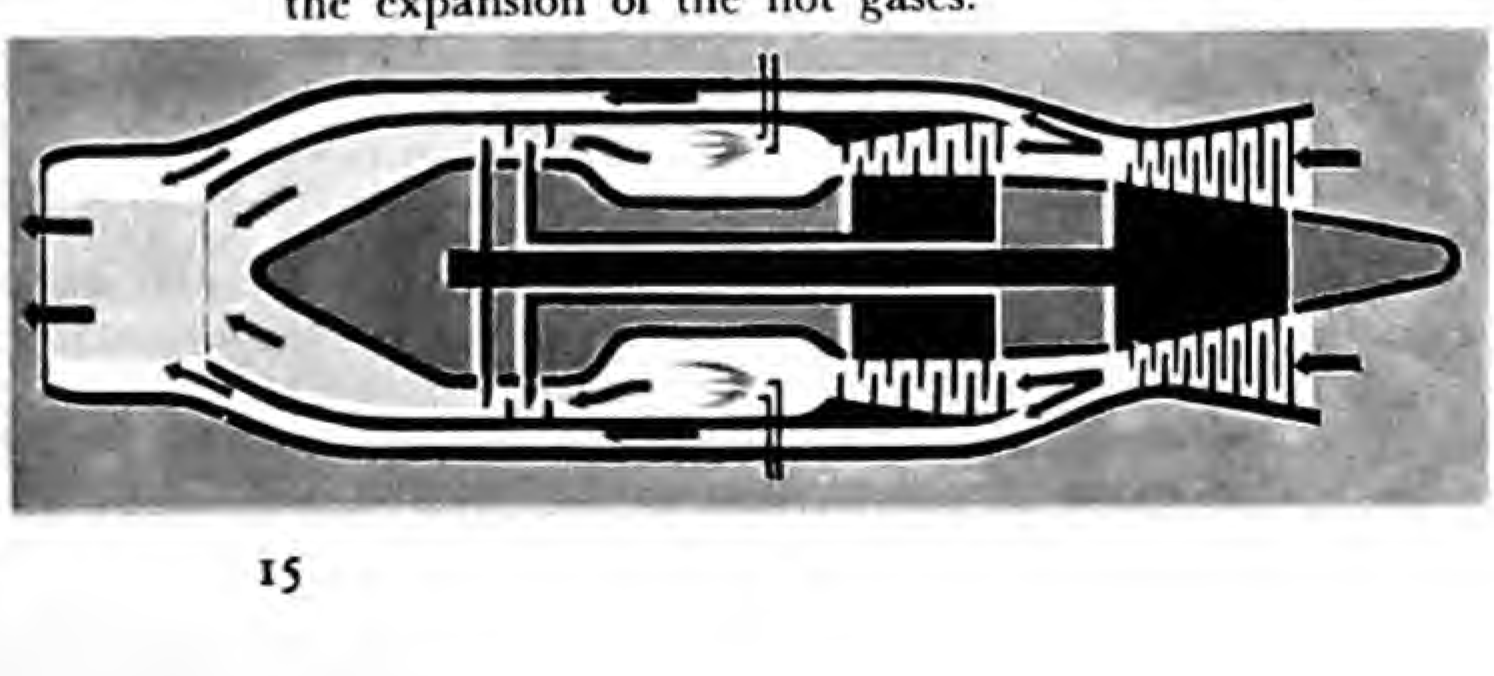
Because of the limitations in the output of power by the piston-driven reciprocating steam-engine, a point was reached when the speed of ships could not further be increased. Then a return was made to an invention 2,000 years old, the turbine, in which there is no piston moving up and down. The steam plays straight onto blades fixed to the driving shaft which then spins round.



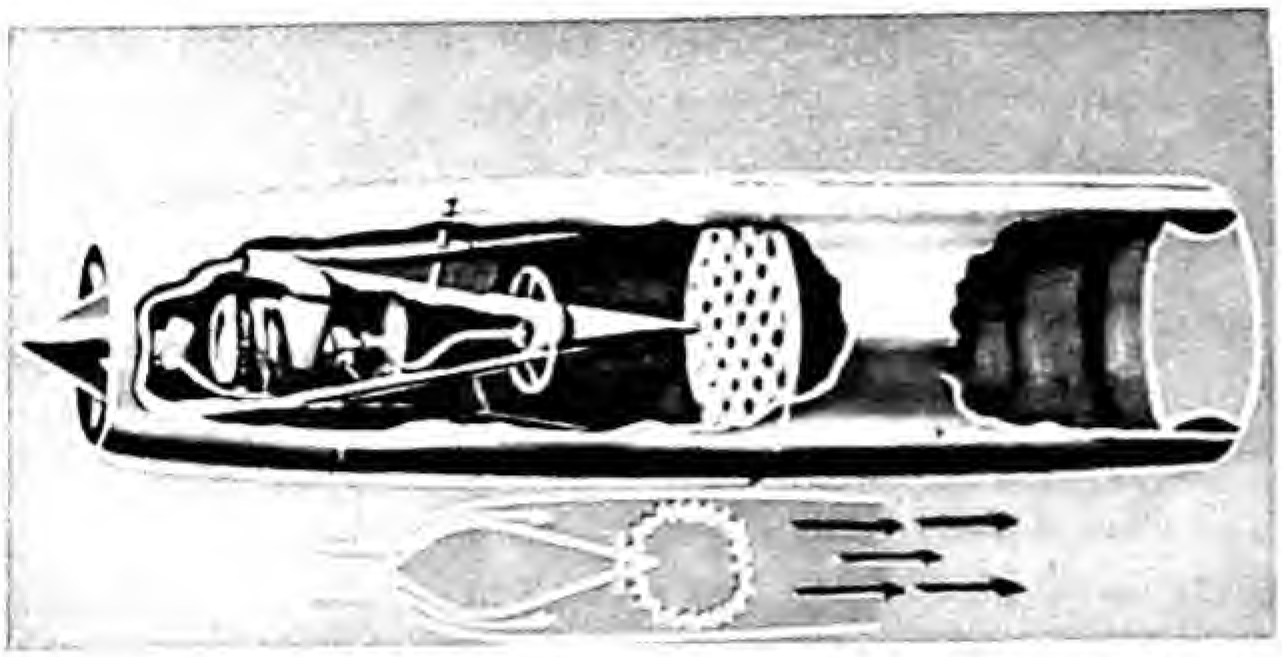
The turbine uses a jet of expanding gas to play against blades on an axle, so turning it. The idea of double and triple expansion was also adapted for turbines; the steam that has passed through a high-pressure turbine, is immediately afterwards put through a *larger* low-pressure turbine.



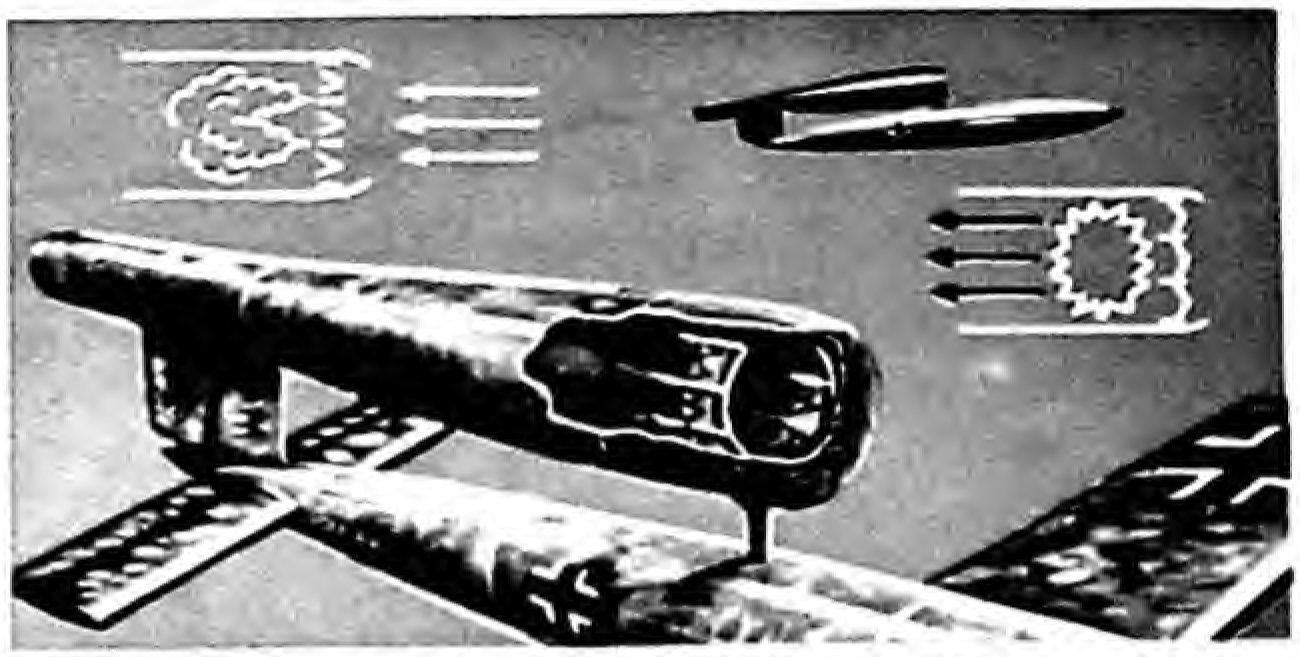
The internal combustion turbine known as the turbo-jet was developed by Sir Frank Whittle. Paraffin fuel burning with compressed air in the combustion flame chambers, thrusts out expanding gases that drive the blades of the turbine round. These are on the same axle as another turbine which forces air *into* the flame chambers, so increasing the amount of air heated by the burning paraffin. And that drives the turbine yet faster, and therefore the compressed air turbine runs faster too. The engine develops its thrust at the outlet pipe from the expansion of the hot gases.



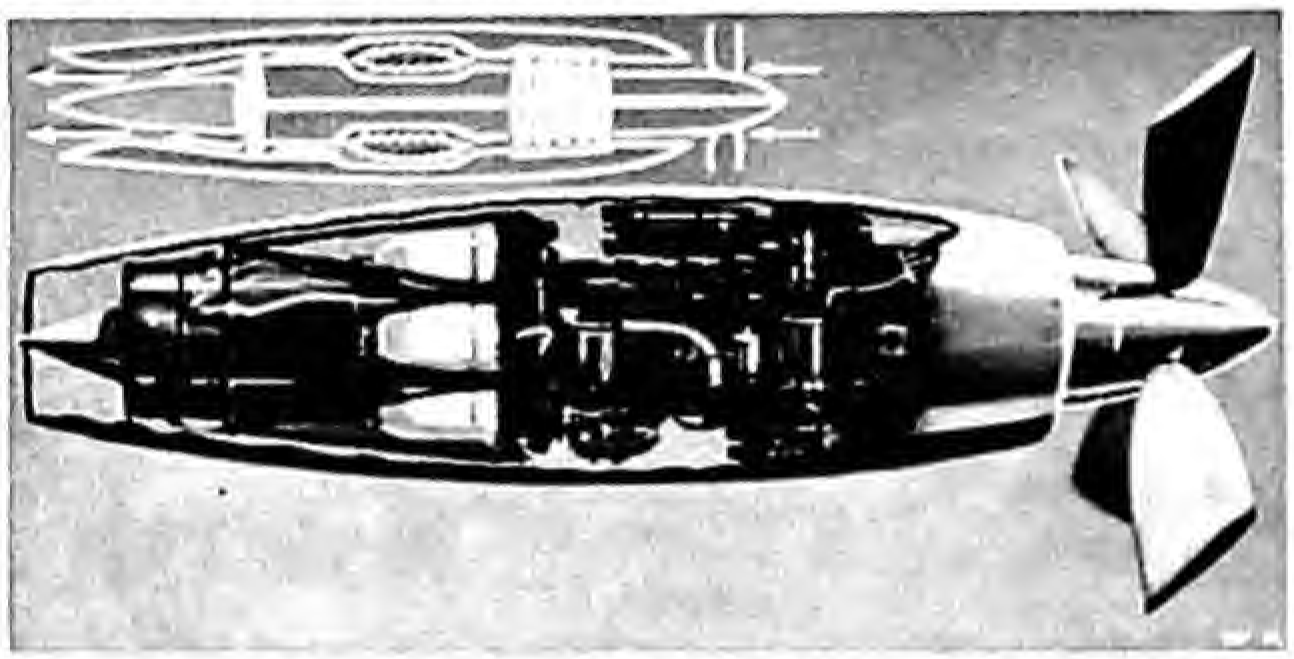
The by-pass jet—a development of the turbo-jet engine—uses a larger turbine for blowing in more air than is necessary for the flame chambers to work at their greatest efficiency. The hot gases from the flame chambers expand the extra air and so increase the thrust. The compressed airflow from the turbine is divided into two trunks; the one containing the "extra" air by-passes the flame chambers and joins the outlet pipe.



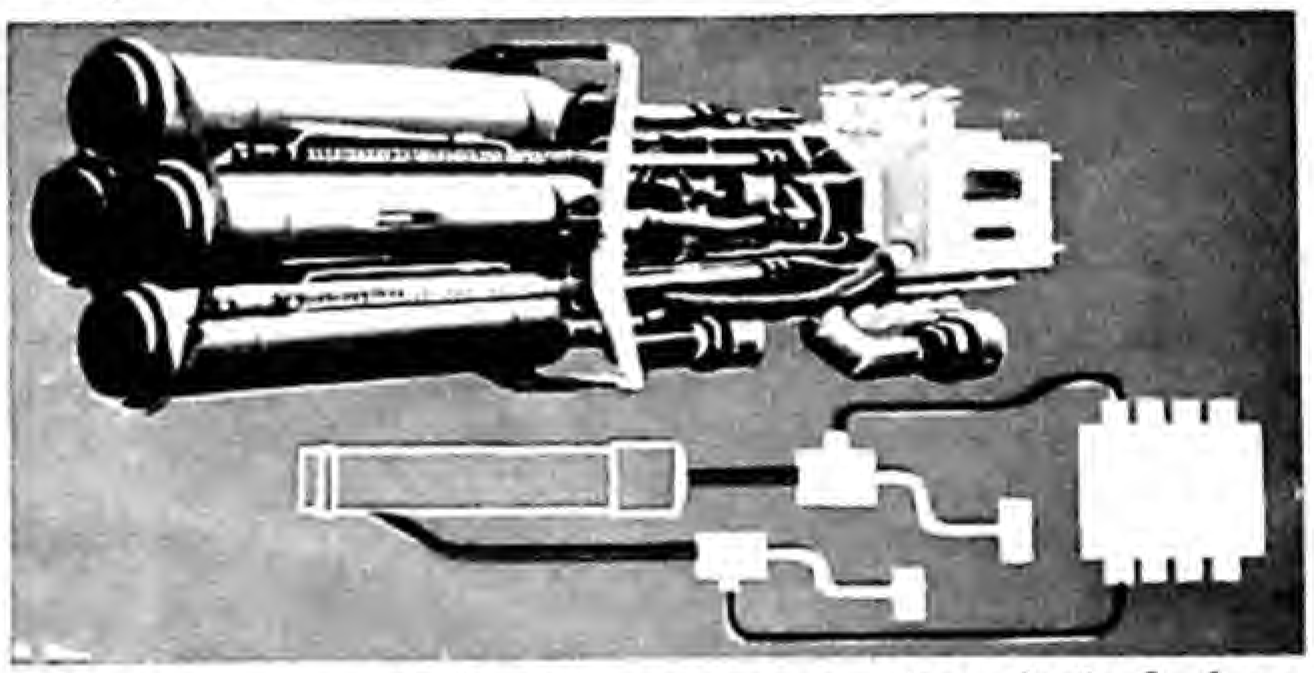
The ramjet or athodyd (aero-thermo-dynamic-duct) will not work at a speed of less than 200 m.p.h. and some other form of power has therefore to be used to bring the ramjet aircraft up to this working speed. When this speed is reached, air is forced in at the front from the atmosphere, fuel is burned in it, resulting in greatly increased pressure and the exhaust gases are expelled at the back while the aircraft is thrust forward. The faster the aircraft flies the greater is the thrust produced because more air can be taken in.



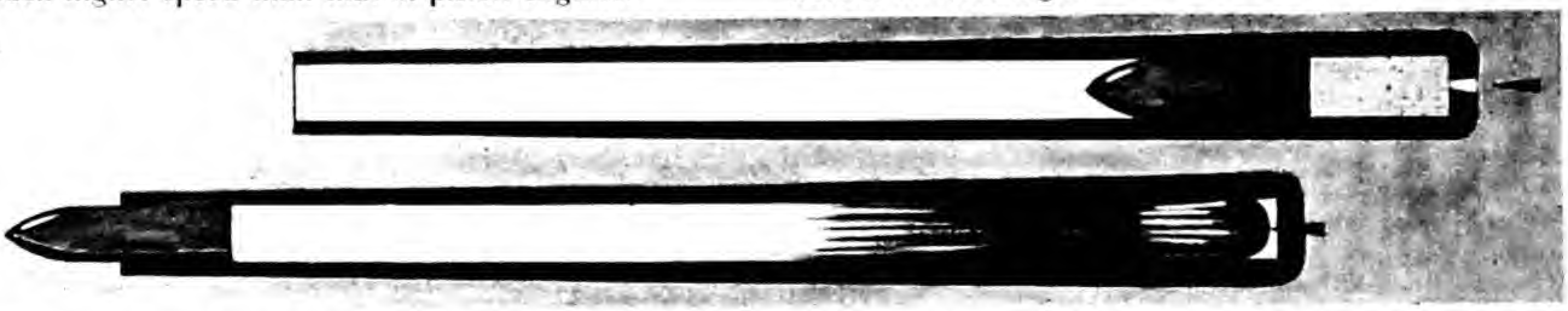
The pulse jet as used in the German V-1 or " flying bomb ". This is similar to the ramjet except that the thrust occurs in impulses instead of continuously. In the German " flying bomb ", a pipe had valves at its front end, which closed automatically when sufficient air had been taken into the combustion chamber. When the mixture was exploded, the exhaust gases were expelled in a jet at the after end, driving the pilotless aircraft forward so letting the pressure in the chamber drop and enabling the valves to open for the next pulse.



The turbo-prop engine developed from the turbo-jet engine. Here the jet of hot gases drives a turbine which in turn drives an airscrew. The turbo-prop engine is fitted with as large a turbine as possible to produce maximum power. At peak output, there is a certain amount of jet thrust not needed to drive the turbine which adds to the thrust produced by the propeller. For civil aircraft this type of engine has the advantage of almost complete absence of vibration combined with much higher speed than that of piston engines.



Rockets carry their own oxygen so that their fuel can burn when flying outside the earth's atmosphere. The fuel and oxygen stored in two tanks, are pumped into the firing chamber, their flow being regulated by the control box on the right. When they are ignited, the resultant expansion of hot gases produces the forward thrust. This is the four-chamber 6,000 lb. thrust Reaction Motors Inc. engine that powered the famous American Bell X-1, the first plane to break the sonic barrier in level flight.

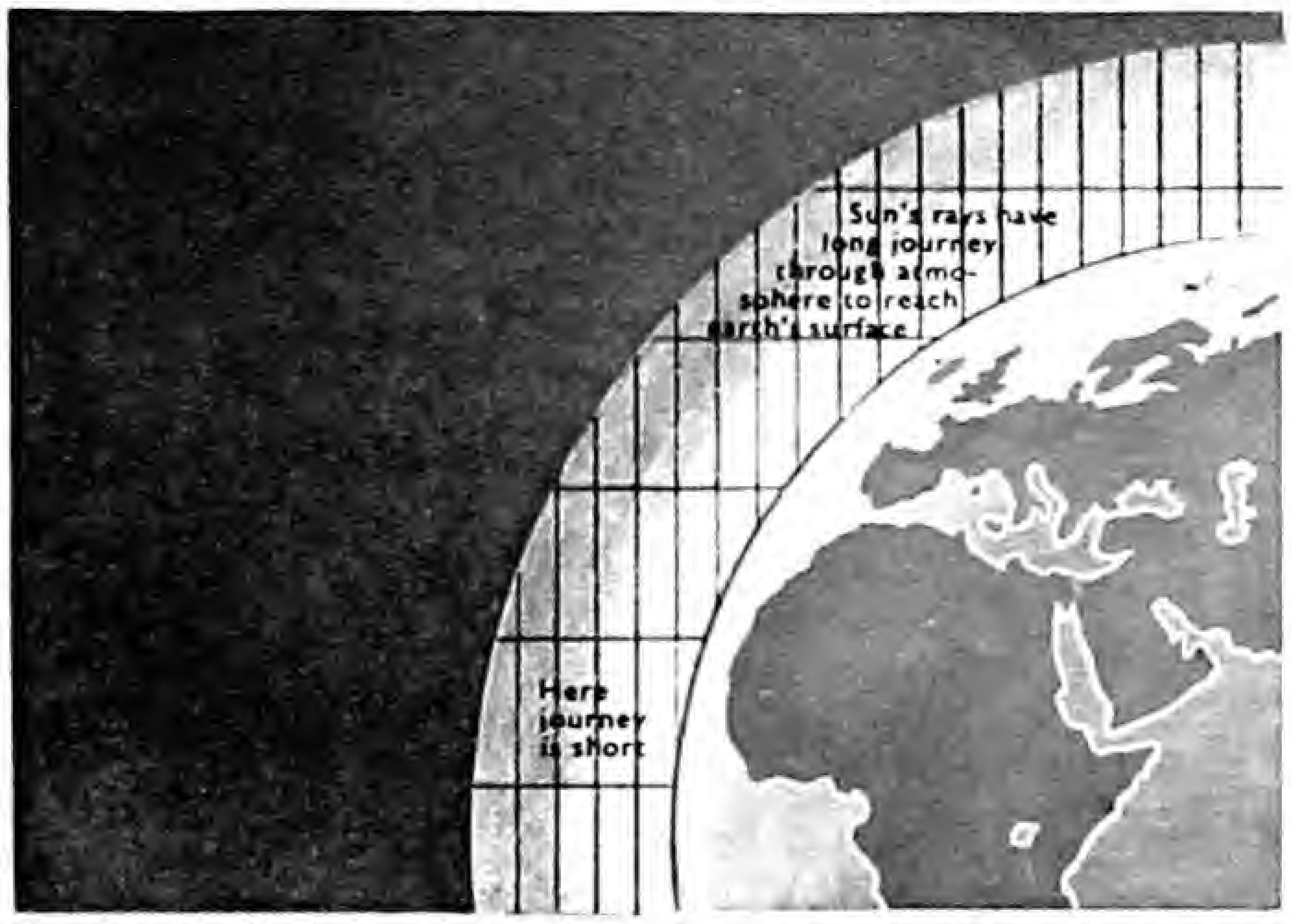


Guns are really much like rockets " in reverse ". When gunpowder (in modern days, cordite) is burned with air in the breech of the gun, hot gases expand. Because the gun is fixed and the shell is free, the shell is thrust out of the barrel at great velocity. A gun, in fact is an internal combustion engine, using solid fuel that contains its own oxygen. Because of the immensity of the gas expansion, recoil is a problem. In a jet aircraft or rocket, the surrounding air and the forward movement of the aircraft absorb it. A gun using modern explosives would destroy any spring used to absorb the shock. Therefore part of the expanding gas is led back into cylinders which act as buffers to recoil pistons attached to the gun barrel.

THE CAUSES OF CLIMATE

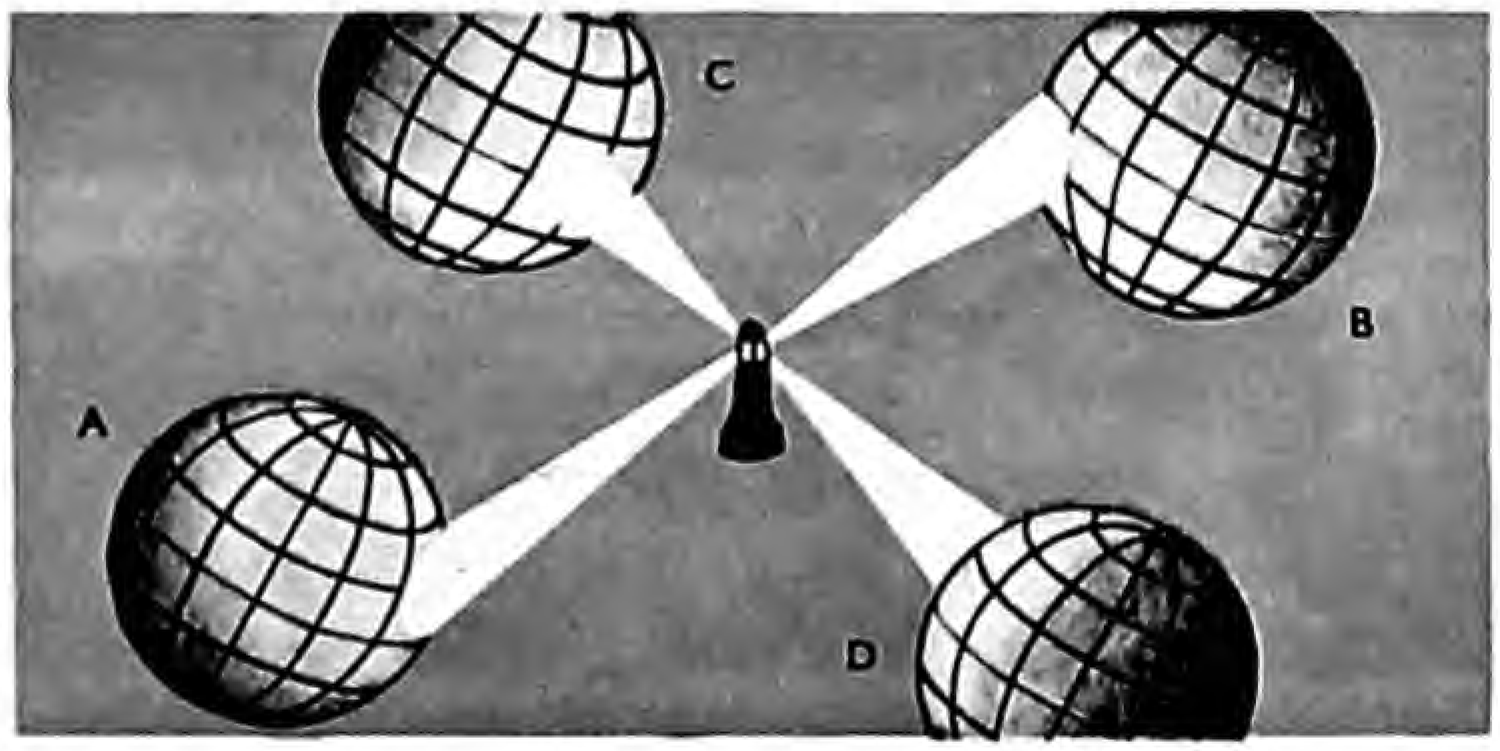
The climate of any place on the surface of the earth is due to the share it receives of the heat of the sun's rays, to the winds blowing over it, and to its position in relation to the sea or land masses.

Enclosing the globe like the peel of an orange the atmosphere is about 200 miles deep, though its densest part is contained in the twelve miles nearest the earth's surface. The great quantities of water vapour in the atmosphere absorb much of the heat of the sun's rays, and which parts of the earth are warmed most by them depends on the effects of the tilt at which the earth spins. At the more northerly and southerly latitudes the sun's rays reach the earth at a slant ; thus they have farther to travel and these areas receive the least warmth.



As the earth is curved the sun's rays (equally strong everywhere as they reach the earth's atmosphere) have to travel further through the atmosphere to reach the earth's surface at places near the poles, than at places near the equator. So they lose more of their heat to the large amount of water vapour that the atmosphere contains, and the poles are always cold compared with the equator.

The earth revolves on its axis once in 24 hours. As night follows day half of the atmosphere cools as it is turned away from the sun and the opposite half turns into the sun's rays.

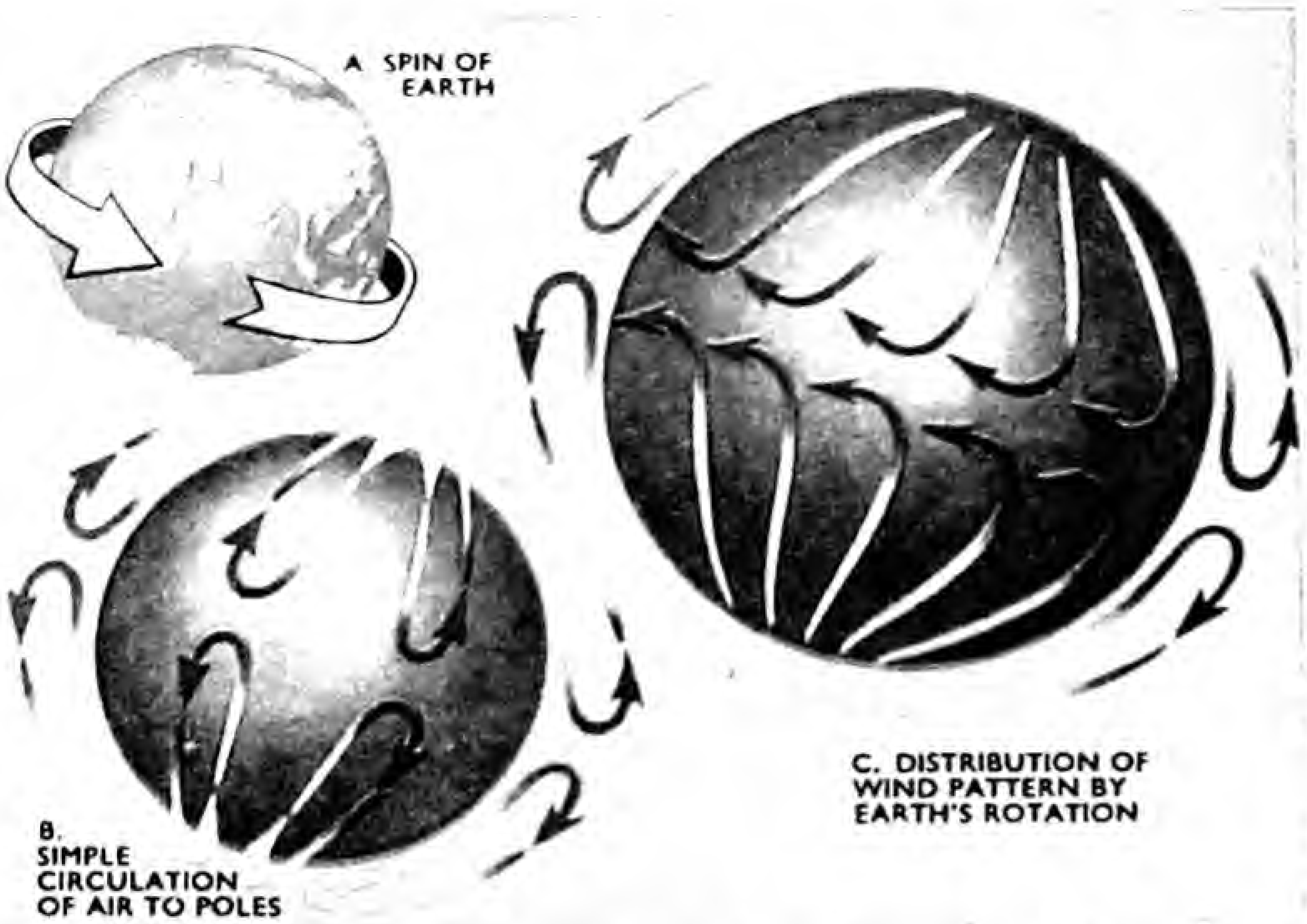


If the earth's axis was at right angles to the plane of its orbit, the ray's of the sun which travel most directly through the atmosphere would fall on the equator all the year round. But because the axis is tilted at an angle of 66½° from the orbit the band round the earth that gets the most direct rays of the sun, and so is hottest part, (represented in the diagram by a lighthouse beam) changes from being 23½° north of the equator (at A i.e. 90° – 66½°=23½°) during the summer of the Northern Hemisphere (when the North Pole is inclined to the Sun) to 23½° south of the equator (at B) when the southern end of the axis is tilted towards the sun. (*See page 157*)

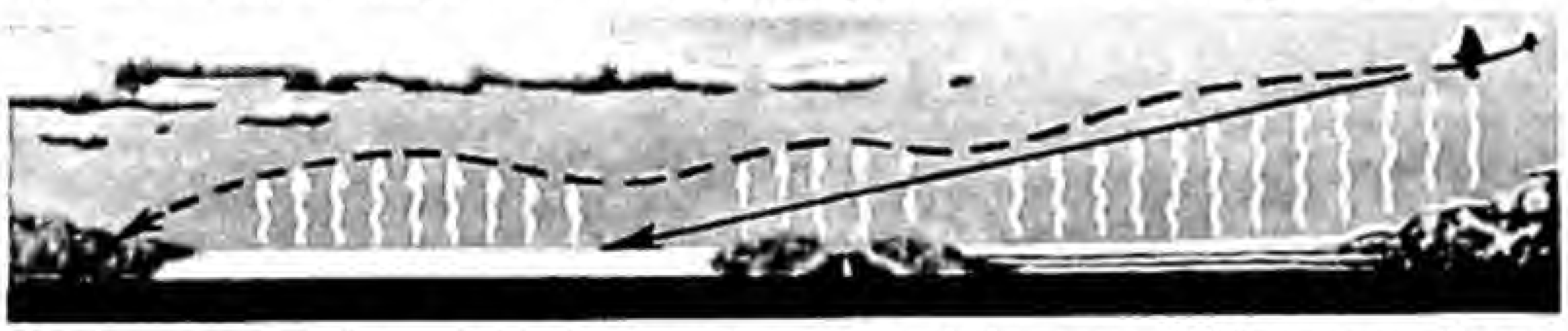
Convection rain. Warmed surface air expands and rushes upwards. On cooling, it falls as rain.

Depression rain. Cold air rapidly lifts warm moist air until heavy rain falls.

Relief rain. Warm wet air sheds rain on rising over mountain to cooler altitude.



Air at the Equator receives much heat from the sun and the warmed air rises and moves towards the poles, cooling as it goes, so that it sinks to the ground at the poles and is drawn towards the Equator again to fill the space left by more hot air rising. The lower picture shows this simple circulation of air. But the spin of the earth deflects the winds and so they form a pattern as in C. The position of land masses would make the true wind pattern more complicated.



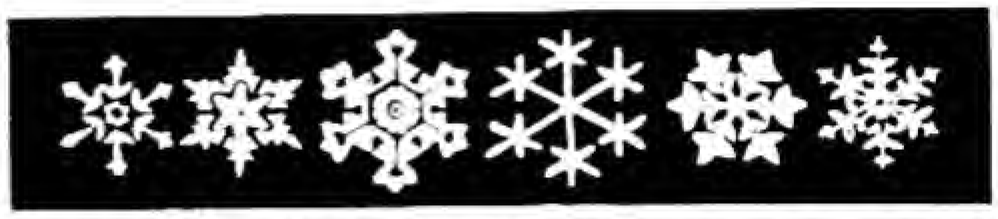
Rising convection currents vary in strength because different surfaces have different heating effects on the surface air. Their varying rate of rise can cause an aeroplane to overshoot its landing field.

Descending air currents are caused by the coolness of some surfaces which, absorbing more of the heat of the sun, cool the surface air. They tend to make an aeroplane land short.

A tornado is a form of revolving windstorm caused by the meeting of a mass of warm tropical air and a mass of cold polar air.

A wedge of warm air is pushed into the cold air. The cold air, circling about the mass of warm air, sweeps right round it, cutting part of it off and forming a storm centre.

Condensation, producing heavy rain, follows. The mass of warm air surrounded by cold air is called an occlusion.



Snow crystals formed when water vapour condenses into ice.

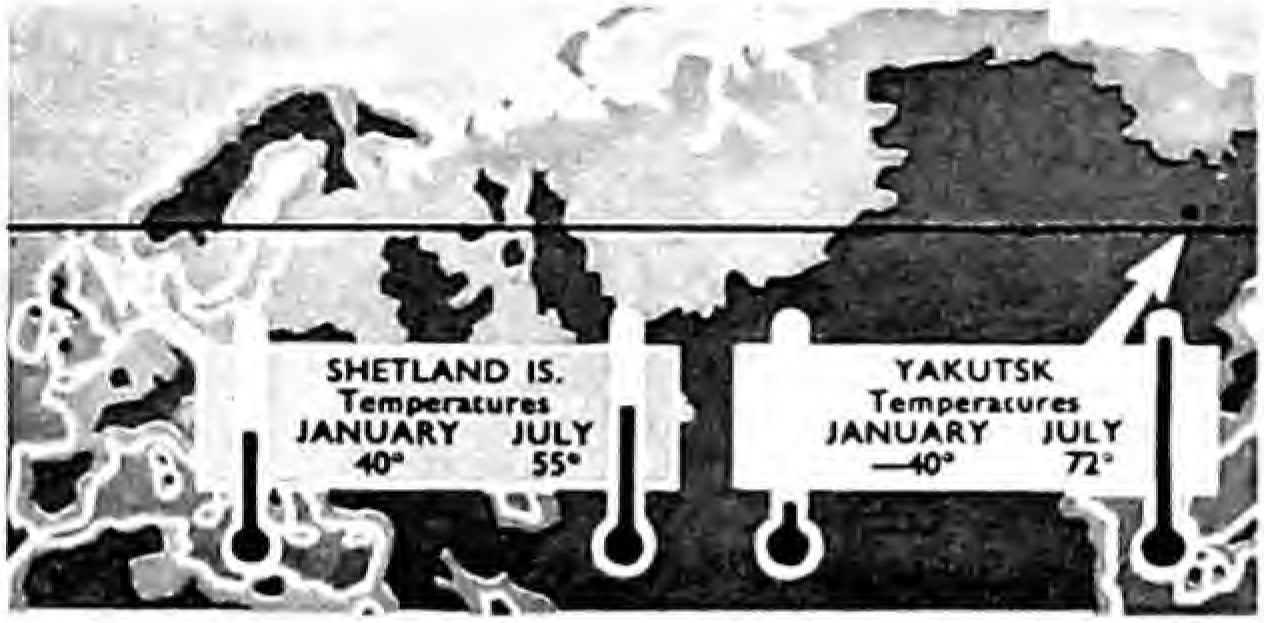
Water vapour condenses as dew when the earth is cooled by radiant heat losses. With the ground surface temperature below freezing, dew becomes frost.

Water vapour condenses on fine particles of dust, smoke or salt from the sea which cooling the surrounding atmosphere make vapour visible as fog or mist.

Cloud is formed when warm air is lifted upwards and, on expanding, cools beyond dew point. The droplets condense on dust particles.

Before they fall as rain, the droplets must increase enormously. A raindrop contains a million times as much water as a cloud droplet.

Monsoon. In summer air laden with water from the Indian Ocean moves towards the low pressure area over the sun heated land causing heavy rain.

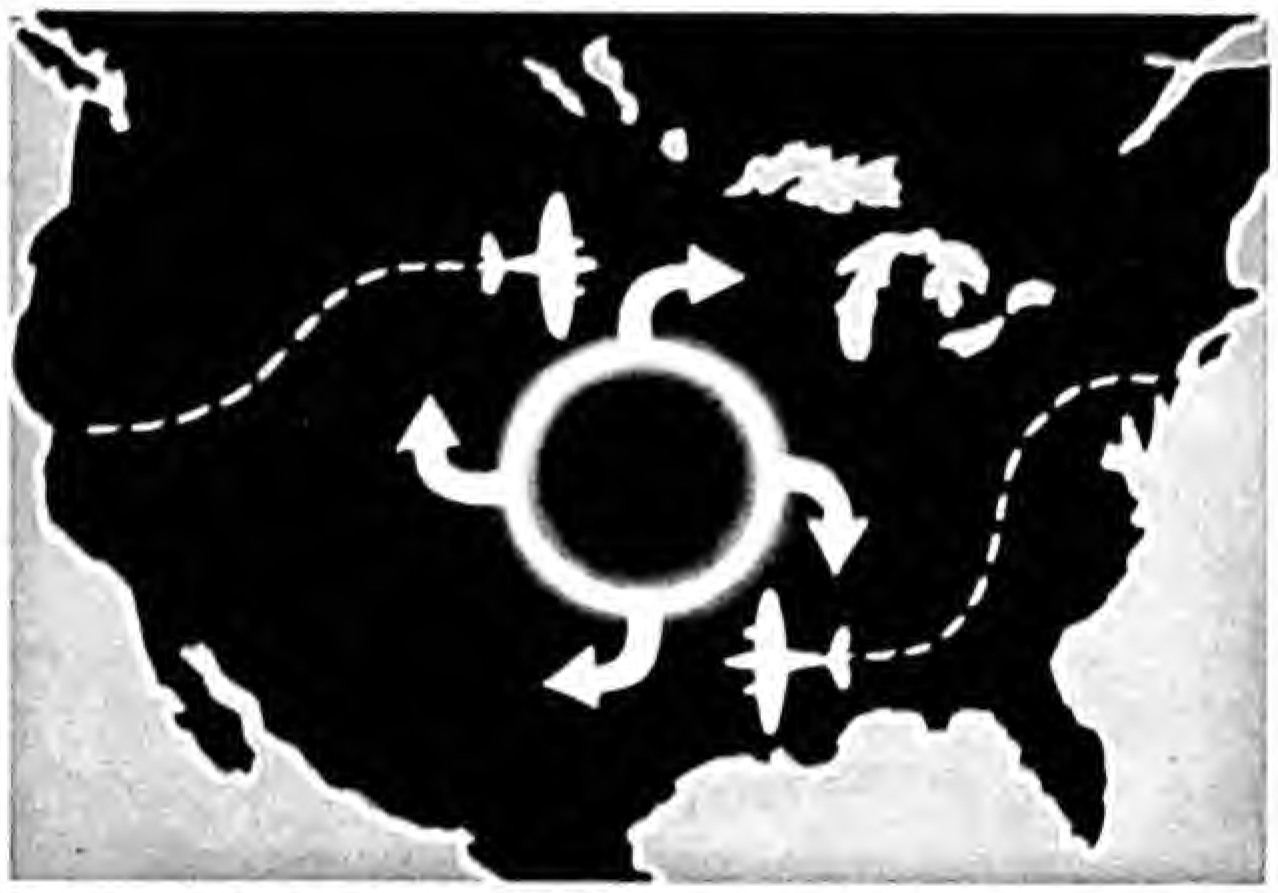


Land heats up more rapidly than the sea and also loses its heat more quickly. Therefore places near to the sea are cooler in summer and warmer in winter than those in the centre of large land masses. Compare the Shetland Islands (Lat 60.30.N) with a variation of 15 degrees only between summer and winter temperatures with Yakutsk (Lat 62.5.N) with its extreme January temperature of $-40°$ a difference of 112 degrees from that of July.

The winds have a profound and complicated effect on climate, and are themselves a complicated result of the uneven heating of different parts of the earth's surface by the sun. The first effect of this is a circulation of air from equator to pole and back, but this is distorted near the equator by the earth's spin. Much the same sort of thing happens with the ocean currents, though they are also distorted by the shape of the continents. Both ocean currents and land masses, according to their temperature at different times, warm or cool the winds that blow over them. For water heats up slowly and cools slowly, while land both heats and cools rapidly.

Places with the sea close around them like the British Isles and New Zealand have temperate climates at all seasons, for the sea stores up heat in the summer, and

Ocean currents which are like rivers of warmer or colder water in the sea tend to raise or lower the temperature of the lands whose shores they wash. The winds that blow over them are also warmed by a warm current and cooled by a cold one. But the winds do not much affect the temperature of the land.



In the Northern hemisphere, air moving out from a region of high pressure, flows in a clockwise spiral and air pilots take advantage of these favourable wind currents. When flying from east to west they would go south of highs and north of lows (anti-clockwise flow). The reverse would be the case in the Southern hemisphere.

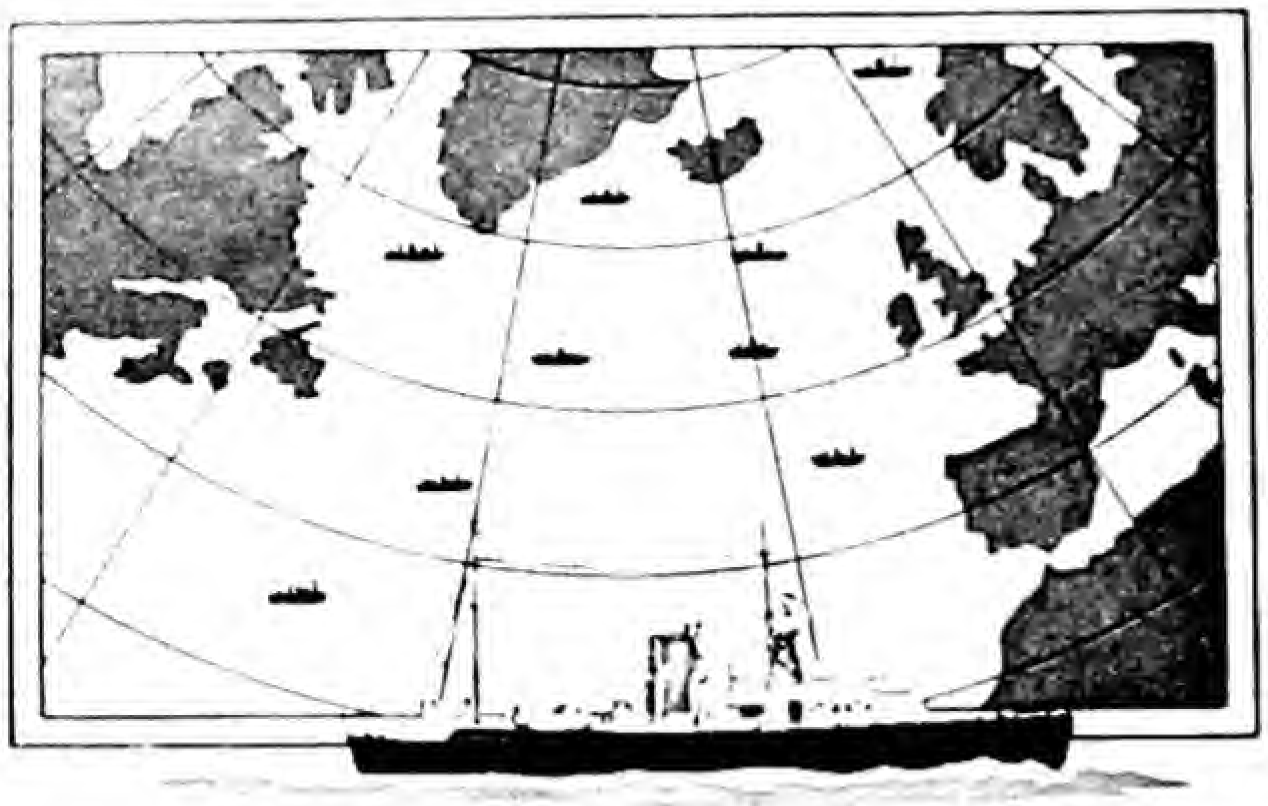
THE FOUR MAIN TYPES OF CLOUD

Stratus, the lowest type

Cumulus, or cloud heaps

Cirrus, the highest clouds

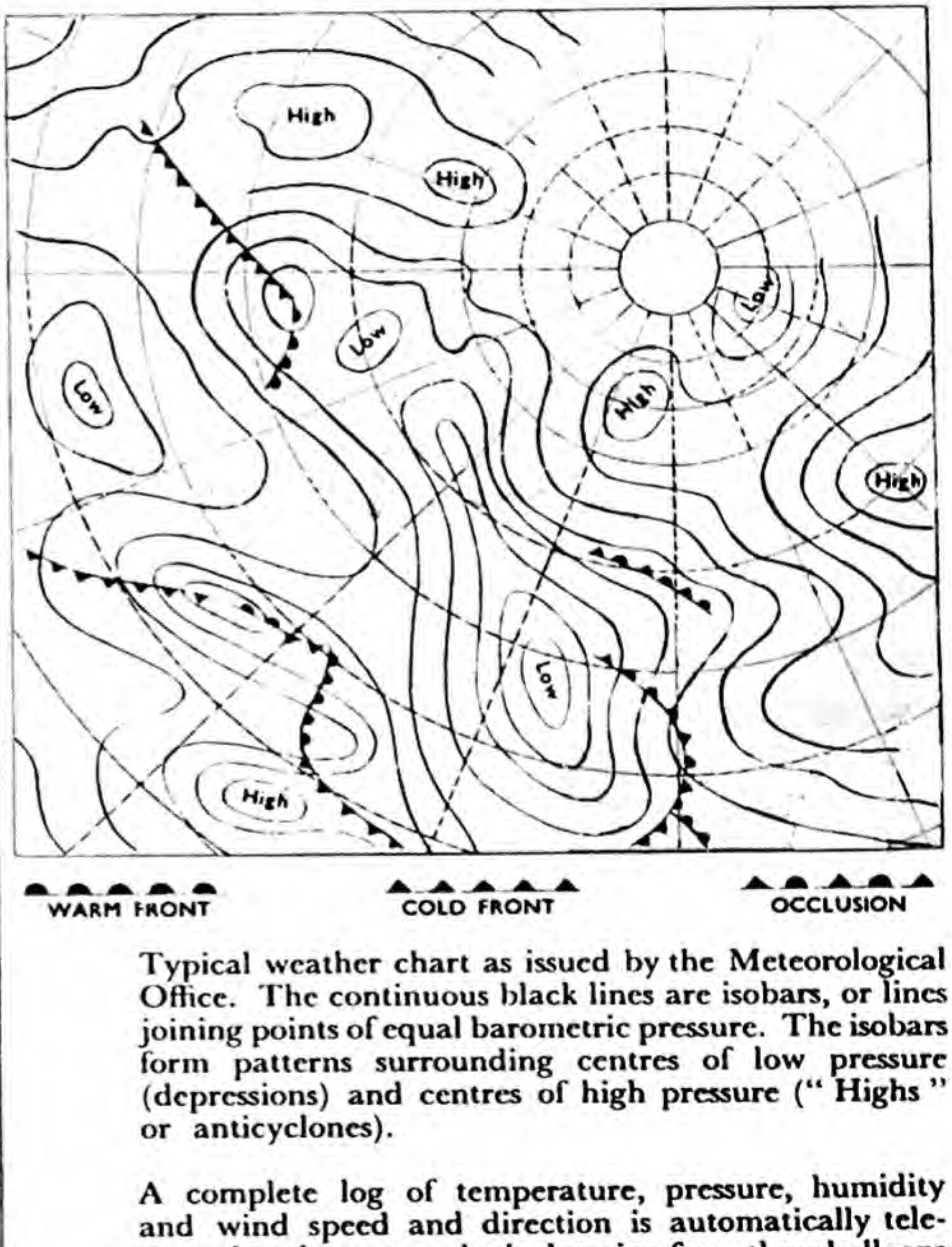
Nimbus clouds foretell rain



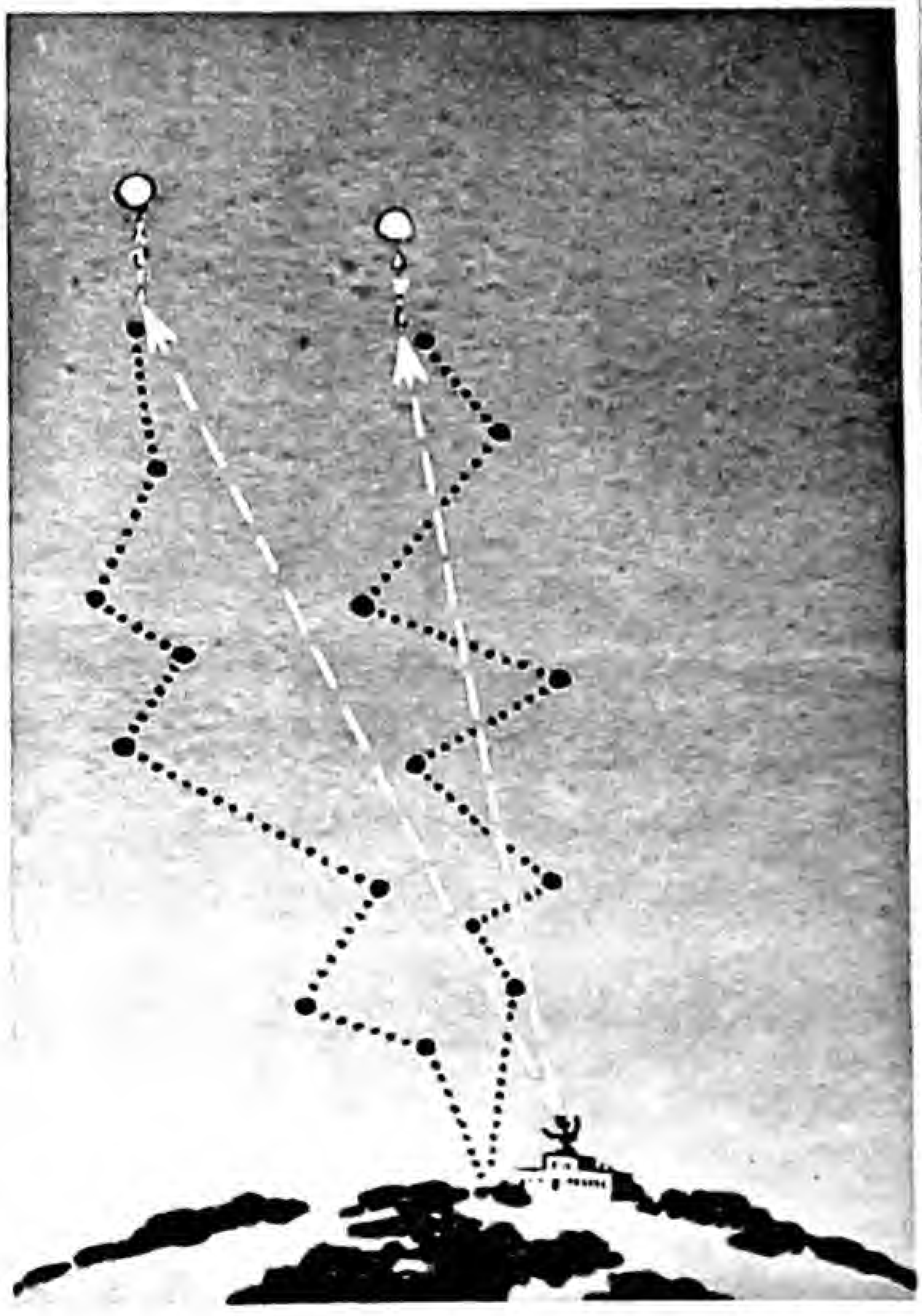
Weather reports are compiled with the help of ocean weather ships stationed in the North Atlantic. Aircraft also make daily meteorological flights to gather information.

loses it slowly in the winter. In the middle of the great land masses very hot summers and extremely cold winters are caused by rapid gaining and losing of heat by the land.

When the heat of the sun falls on land or sea it evaporates into water vapour some of the water on the surface. The winds carry this water vapour, collecting more and more of it as they go along, until they meet an air mass cooler than themselves, and the water vapour condenses to fall as rain. The driest regions of the world occur where winds blow continuously in one direction over a land mass, pick up moisture without meeting cool air at a sea coast, or being forced to higher and cooler altitudes by a range of mountains.



Typical weather chart as issued by the Meteorological Office. The continuous black lines are isobars, or lines joining points of equal barometric pressure. The isobars form patterns surrounding centres of low pressure (depressions) and centres of high pressure (" Highs " or anticyclones).

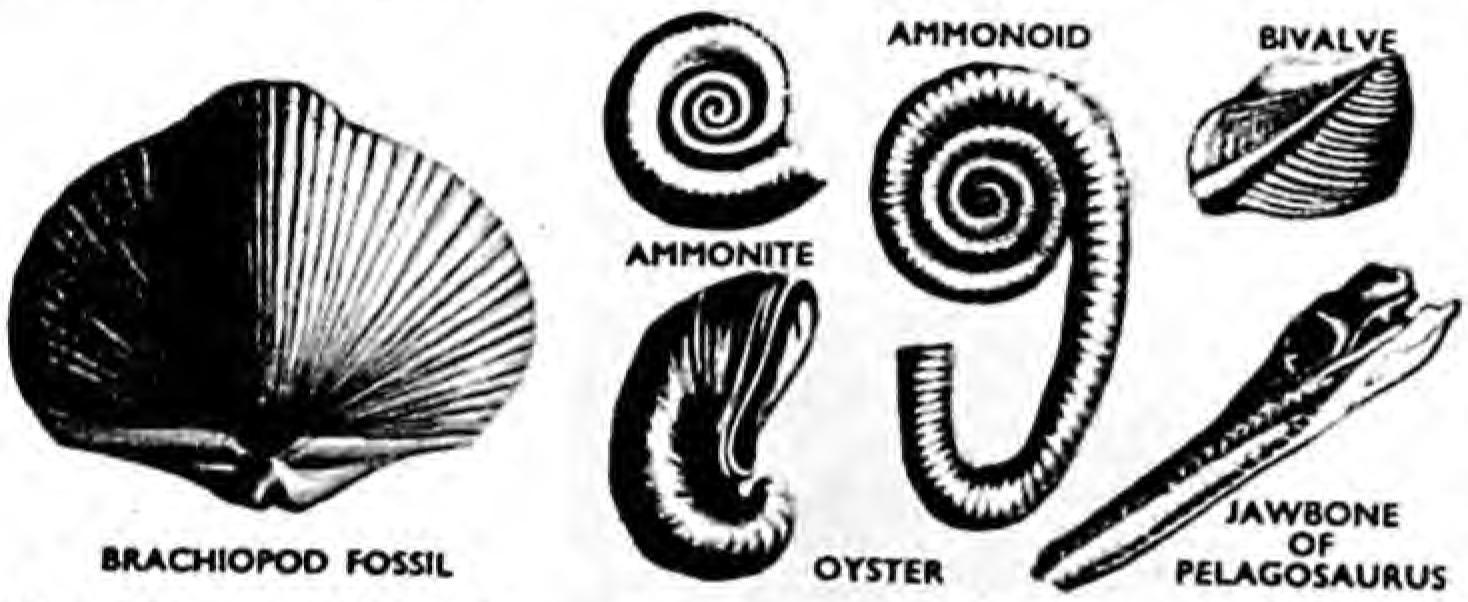


A complete log of temperature, pressure, humidity and wind speed and direction is automatically telemetred to the meteorological station from these balloons every 15 seconds during their ascent. Radar checks their position when they send each signal so the pattern of conditions in the upper air can be estimated, and future trends anticipated. When the balloons burst on reaching their maximum altitude, the apparatus descends by parachute but continues automatically to answer signals from the ground station. In this way accurate information about weather conditions can be supplied to ships and aeroplanes.

THE MYSTERY OF THE ROCKS

Water must have laid down these layers of sand and mud revealed in a sandpit.

Tiny sea creatures are still making layers of chalk at the bottom of the sea.



Many forms of life of long ago are preserved in rock as fossils. If fossils that lived only between certain times are found in rock in two different places, both must have been formed at the same time.

How the earth's surface got its shape remained a mystery until rocks, which were exposed by natural means, or by quarrying, had been carefully studied and compared with the results of processes that are happening in nature today, such as a river mouth silting up or the sea wearing away a cliff.

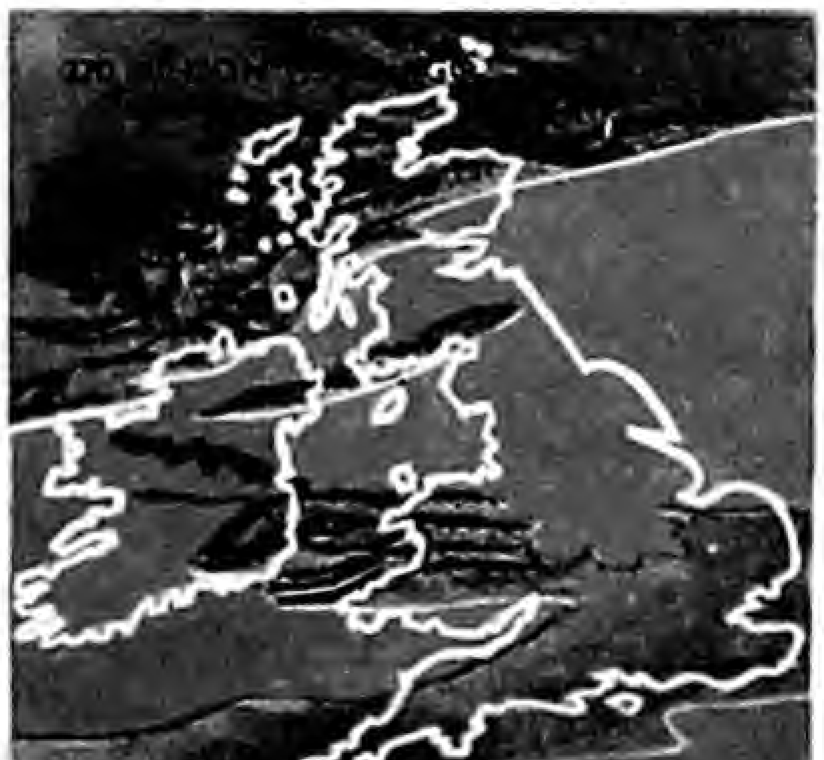
Rocks often occur in layers. On present day beaches we can see how shingle, sand and mud, sorted out by the sea (*see page* 181) are being laid down into layers from the sediment of the sea. Such layered rocks are called sedimentary and usually contain plant and animal remains (fossils). Of course, the lower the layer the older it must be. The fossils in each layer are of creatures of different periods. The age of rocks can be told by a study of its fossils.

The Making of a Land

The outline of the British Isles, formed over millions of years, is still changing. Land movement, weather and water action have all played a part.

Cambro-Silurian. At this time a deep sea trough ran across Britain covering all but the south of England. Mountain ranges were being slowly formed. The land was barren, only in the sea was there plant or animal life ; these provided the earliest recognizable fossils.

Caledonian. A period of mountain folding in the Scottish Highlands, the Lake District and North Wales. Sea covered Devon and Cornwall, laying down deposits of sand and shale, later hardened into quartzites and slates. Plants and some kinds of invertebrates were on the land.



Carboniferous Limestone. The sea once more flowed across Britain leaving southern England and parts of Wales and Scotland as land. The limestone of the Mendips and the Pennines was formed. Swamp plants of this and the next period decayed to form the coal fields.

Millstone Grit. The land around Scotland rose once more and the rivers flowing south brought with them sand and pebbles to form the layers of grit and shale in the Ilkely, and Peak districts. Some of these layers are as much as 5,000 ft. thick.

Permian. Most of the British Isles was now part of a land mass. In its centre was a low desert plain of red sand. In Devon and Somerset, still under the sea, rich red clays were laid down. Reptiles, both flesh and leaf-eating roamed the land.

Lias-Jurassic. Shallow seas, swarming with giant reptiles, now covered most of Britain, laying down beds of limestone and clay. Some reptiles, such as the pterodactyl, began to fly. The limestone can be traced from Somerset to Yorkshire.

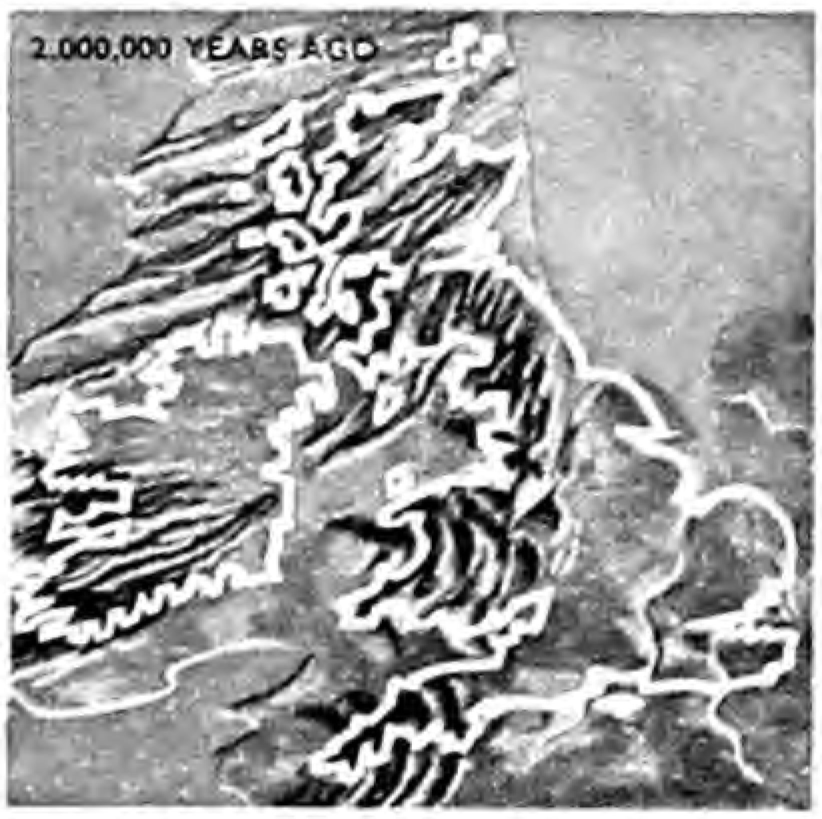
Lower Cretaceous. The raising of the land again left an arm of the Northern Sea. The freshwater Wealden Lake covered parts of southern England. It laid down the Weald clay from Folkestone to Guildford.

Huge reptiles roamed the Jurassic deserts of Britain. Some, like the clumsy leaf eating Iguanadon, were harmless to other creatures and took to the water when danger threatened ; others, like the fierce flesh eating Allosaurus, preyed on their weaker rivals. The flesh eaters usually walked on their hind legs, thus their forelimbs could be used for seizing their prey. Here an Allosaurus attacks a heavily armoured but otherwise helpless Stegosaurus, while Ramphorhynchus, flying reptiles, wheel overhead.

Upper Cretaceous. Thick beds of chalk confirm that again the sea flowed over the land. These beds cover most of southern England and small areas of northern Ireland. Plants began to resemble more closely those we know today.

Eocene. All of the present day British Isles was now dry land except the south east. Layers of clay, brought down by many rivers, formed where London now is. Volcanoes were erupting in Skye and on the Isle of Mull.

Pliocene. Conditions were now more settled with the sea gradually draining away from the land ; but a subsidence in the north-east enlarged the North Sea. A colder climate brought with it new forms of plant and animal life.



With its thick steamy jungles and mangrove swamps Eocene London looked rather like present day Malaya. Crocodiles lurked in the rivers with turtles and exotic fish, while tiny eohippus, a forerunner of the horse, and elephants roamed the land. When the climate grew colder many of these animals disappeared to warmer lands leaving behind only those better able to withstand the cold. The armoured huge reptiles of the Jurassic times were now extinct.

Late Pliocene. The North Sea continued to widen. The old mouth of the Rhine ran along the coast of East Anglia, depositing sand and clay in these areas. Elephants still roamed the woodlands. The climate was similar to that of today.

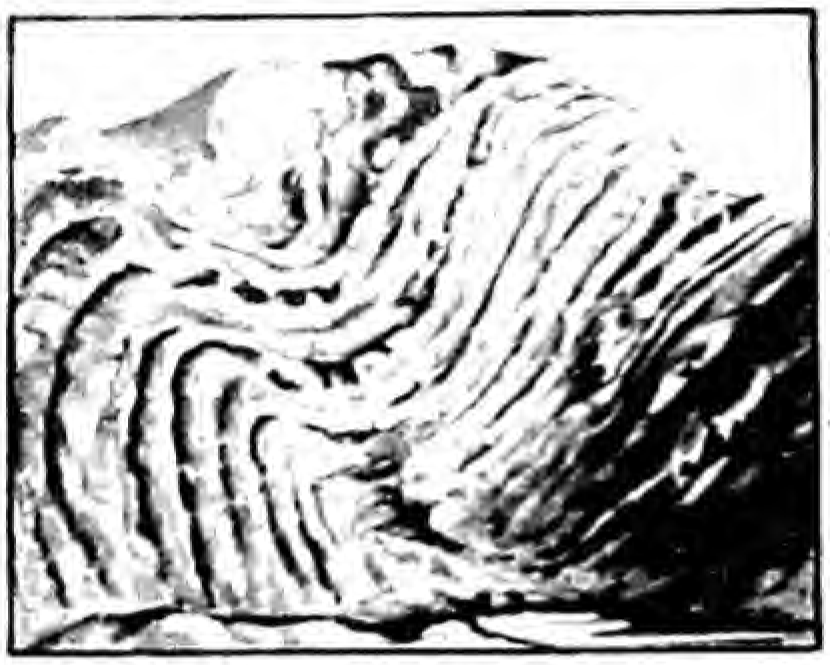
Pleistocene. Great Britain's shape was probably now very much like that of today but narrow corridors still joined it to France and Ireland. A vast ice floe covered the country during each ice age, gently moulding the rugged landscape.

By the Pleistocene age, primitive man had spread into Europe from Asia and Africa. Living in caves and wearing animal skins to withstand the cold, he made stone tools and killed deer, bison and the long haired mammoth elephant for food.
The walls of his cave were decorated with animal paintings and scenes which help to show us how he lived. The paintings are evidence of a fair degree of development. The vast ice floes covered Northern Europe and North America.

Why do the layers look like this today?

It is sometimes possible to see layers of rock standing straight up like these on the Isle of Wight. This is proof that at one time great earth movements tipped the layers on to their side. The coloured bands of sand on the left are those of Alum Bay. The chalk stacks on the right are The Needles which have been isolated from the mainland by wave action.

Other earth movements sometimes cause the rock layers to crack and slide out of position. This is called faulting. Such movements may be accompanied by earthquakes. The dropped side of the fault is the downthrow side, the other the upthrow.



Fold. A bend in the rock layers of the earth's crust. It is caused when great pressure is applied at each end of the strata (rock beds) during an earth movement and results in them being literally folded up and crumpled. A fold is composed of an anticline and a syncline (*see page* 26).

Sometimes the pressure is so great that part of a rock layer is pushed on top of another part of the same layer. This is called an overfold. The rock layers which were last laid down will be found under earlier ones. The N.W. Highlands of Scotland show well marked overfolding.

A rift valley is formed when the land sinks between two or more parallel faults. It is very long and narrow in proportion to its width. The Rhine Valley and the Central Lowlands of Scotland are two examples in Europe. The Jordan and the upper Nile Valley are other examples.

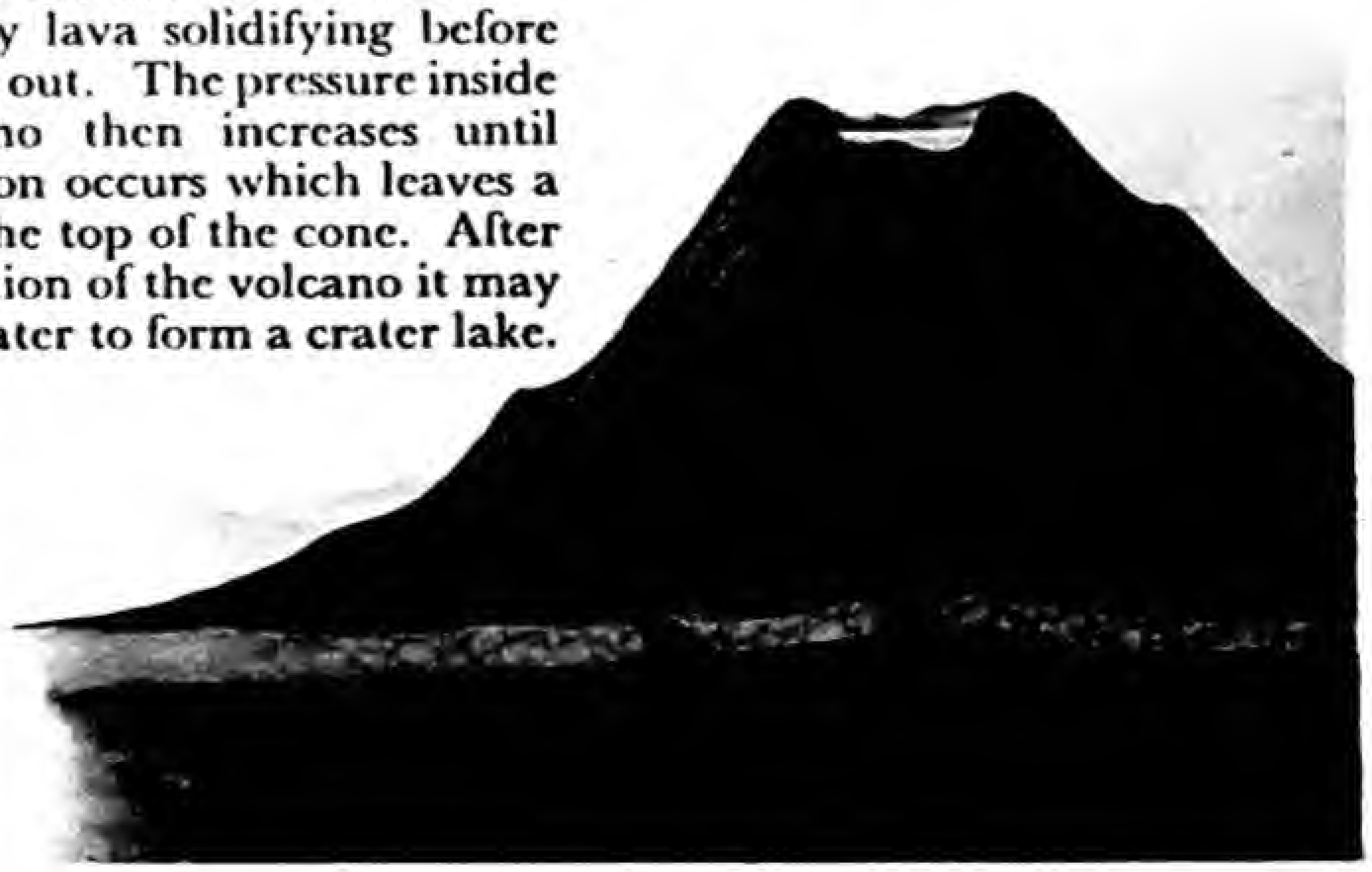
A volcanic plug is a pillar of igneous rock once the lava cone of a volcano. The softer rock surrounding it has worn away to isolate the plug. Edinburgh Castle is a well known example.

Dyke. Molten lava from a volcano, which has forced its way to the surface along a fault or between rock beds, after cooling may weather out as a narrow vertical edge of rock.

Laccolith. Molten matter from the earth's interior unable to reach the surface collects in a blister and cools below layers of rock. Later the action of the weather exposes it as a dome shaped feature. Dartmoor is an example of an old laccolith.

Volcanoes

Volcanoes are holes in the earth's surface through which, at various times, hot molten lava pours. The familiar cone of volcanoes like Vesuvius is made up of cooled lava and ashes surrounding the crater.



Sometimes the neck of a volcano is plugged by lava solidifying before it can pour out. The pressure inside the volcano then increases until an explosion occurs which leaves a crater at the top of the cone. After the extinction of the volcano it may fill with water to form a crater lake.

Peneplain. The final smooth skyline to the landscape after erosion over millions of years by various agents such as glaciers, rivers or the sea has levelled it.

Slip faulting. The sliding down from a cliff face of areas of rock or soil. This slip fault on the coast has been caused by the sea undercutting the rock face.

Raised beach. A second beach that occurs above the level of the normal beach ; a result of the raising of the land by earth movement or of the sinking of the sea.

Erosion

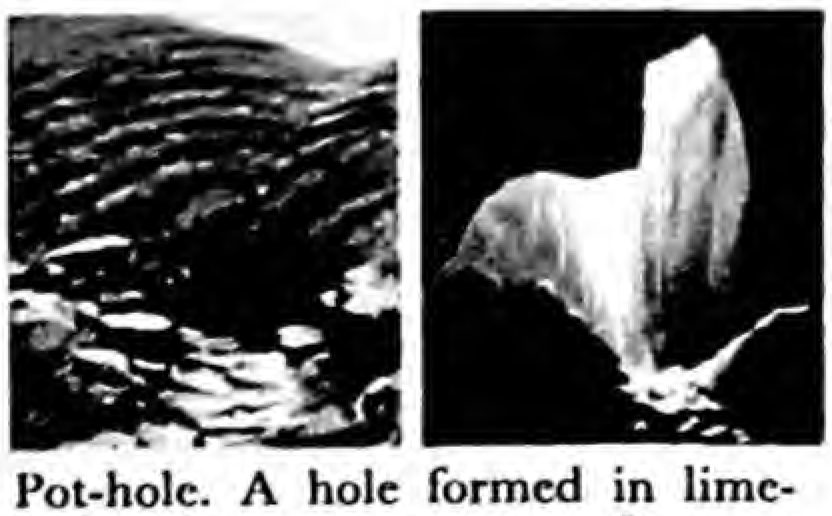
Erosion is the eating away of the land surface by agents of the weather, water, wind and frost.

Young river valley. The upper course of a river. Swiftly moving, the stream cuts deeply into the ground and carries along boulders to the lower reaches.

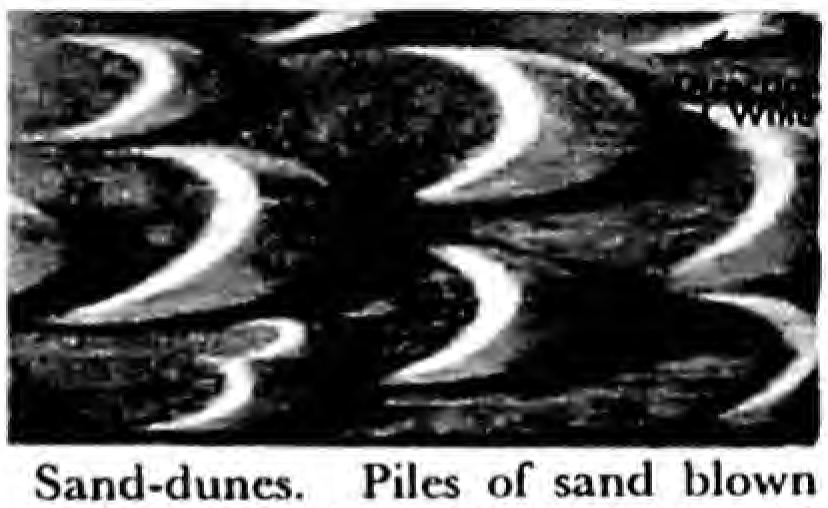
Mature river valley. The lower course of a river as it meanders slowly across a plain. Here it widens rather than deepens its bed and carries only fine sediment.

Glacier. A slowly moving river of ice. The ice carries within it boulders which at the melting snout are dropped as heaps called moraines.

Glaciated Valley. Valleys are normally shaped crosswise like a V. But where they have been occupied by a glacier, the sides have worn to a smooth U shape.



Pot-hole. A hole formed in limestone when a stream of water plunges into a crevice, which it slowly widens by dissolving the rock. Left is the outside of a pot-hole, and right the inside.



Sand-dunes. Piles of sand blown up by wind eddies. Crescent shaped barkhans seen here are formed by gentle winds. If not fixed by vegetation dunes creep forward like slow motion waves.

Geological Terms

Geology is the study of the history of the earth. These are some of the common words, with their meanings, used by geologists.

Rocks which have been formed into layers by the depositing of silt, sand or stones in water, or by wind, are known as stratified rocks. This is at Muckross Head.

Anticline and Syncline. Rock layers folded up into an arch make an anticline, while the curve of a downward fold is a syncline. Slow earth movements cause folding

Dip and strike. The visible slope of tilted rock layers is known as dip, while the strike is the line along which it cuts the ground. Often accompanied by folding.

Butte. An area of hard rock left after the softer rock around it has been worn away. It is further shaped by wind and rain into a narrow pillar.

Mesa. A mesa is similar to a butte, but erosion has not gone so far, and it is a much wider pillar. There are many buttes and mesas in Arizona.

Cuesta. A steep fronted hill of dipping rock layers (here behind foreground earth pillars). The scarp slope is eroded more than the dip slope.

Delta. The land formed by deposits of sand and silt brought down by a river and laid at its mouth under conditions where the tide is not strong enough to remove it.

Meanders. The winding course that a mature river takes. The water swings in curves wearing away the banks. Loops may be cut through and an ox bow lake formed.

Stalactite. A cone from which limestone solution drips.

Stalagmite. A pillar formed where limestone solution drops.

Earth Pillars. Formed by the action of rain on clay cliffs.

Scree. A skirt of rubble eroded from a cliff face.

Coral atoll. A fringe of land built up by the successive generations of coral polyps growing around a mountain submerged in the sea. When the polyps die their stony bases, being of lime, do not decay.

Geyser. Found in regions of recent volcanic activity. Ground water collects in rock crevices. Heated by lava, it turns to steam and throws out the water on top of it in jets.

Roche Moutonnée. Rocks where there was once a glacier. Jagged towards the glacier's snout and smooth and rounded on the uphill side where the ice rode over them.

Cirque. Also called corrie or cwm. A rounded basin in glaciated mountains, sometimes with a little lake. It has been formed by a small glacier in a valley head.

Canyon. A steep sided valley formed where a river erodes down into the rock faster than the valley is widened by erosion. This is the Grand Canyon, Colorado.

Gorge. Like a canyon it is a steep side valley cut by running water. Gorges are common in limestone country. This is Cheddar Gorge, Somerset.

Dust storm. Caused by a strong wind blowing over an area of dry, dusty land. The wind carries the dust along in thick clouds and drops it when it dies down.

Granite Tor. When granite weathers, harder parts are often left as isolated rounded masses known as tors. There are many tors on Dartmoor.

Arete. The sharp edge on the col between two glacial valleys or corries (*see page* 26). There are many in the mountain areas of Scotland and Wales.

Fjord. A long narrow coastal inlet of the sea with very steep sides formed by glaciers cutting down to sea level. There are many of them around the coasts of Norway, Canada and New Zealand. A submerged moraine is found at its mouth (*see page* 25).

Unconformity. A layer of newer rocks lying at a different angle on older ones. This happens when layers sink beneath the sea and have new layers laid across them.

Drumlin. A small rounded hill of boulder clay on land that was once covered by a glacier. Like moraines they are left behind when the ice melts.

Glacial lake. Either a lake filling a rock basin that has been dug out by a glacier, or filling a U shaped valley plugged by a moraine.

Levee. A bank built of sediment above the general level of a river during flooding. Higher layers are left with each flooding.

Hanging valley. The steep ended remains of a spur after a glacier has cut across a side valley. Marked by a waterfall.

Loess. Dust or fine soil, sometimes from a desert, blown by wind over great distances.

River terrace. The flat plain left when a river cuts down through its old flood deposits.

Metamorphic Rocks. Rocks in the earth's crust changed under pressure or heat. Granite is turned into gneiss, clay into slate, limestone into marble.

Alluvial fan. Sediment carried by a swift running stream is laid down as the stream flows into open water. It is in fact a freshwater delta.

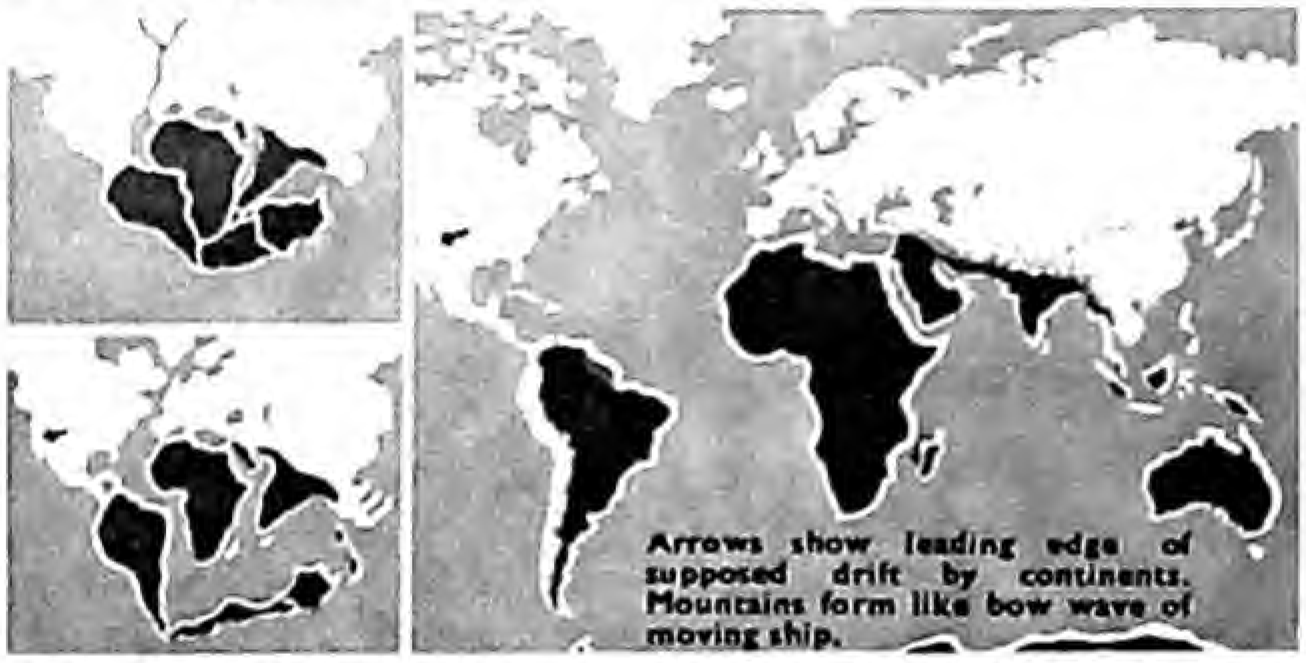
Ice-dammed lake. A lake in a side valley whose outlet is blocked by the ice of a glacier in the main valley.

Wave cut platform. Cliffs retreat because of sea erosion. Their lower parts if hard enough may persist on the shore as a rocky wave cut platform.

Sea Stack. A pillar of rock once a part of the mainland. It became isolated when the movement of the waves wore away the softer rock between.

Truncated spur. When a glacier moves down what was a river valley, the spurs formed where the river meandered are cut off and made steep sided.

Col. A pass high up on the skyline of a mountain range, formed where erosion eats back from both sides and so indents the ridge.



Continental Drift. The general similarity between the eastern and western shores of the Atlantic led a scientist called Wegener to assume that at one time these coast lines had fitted together like pieces in a jigsaw and had later drifted apart. This theory is called continental drift and assumes that the fully cooled rock of the continents is 'floating' on the still fluid basalt below it. No one yet knows whether the theory is correct. The arrows show the edge of the supposed drift by continents.

Sea Cave. A hole in a cliff-face made when waves throw up pebbles against it and gradually tunnel away the softer portions of the rock.

Natural Arch. A bridge of rock cut by natural means, often by a stream cutting through a soft rock like limestone. This is Rainbow Bridge, Utah.

Lagoon. A stretch of water separated from the sea by a strip of land formed by coral polyps or by mud and shingle.

Corrie Precipice. The steep ice cut wall descending from an arête into a cirque.

Badland. A dry, treeless area, pitted with gullies formed by occasional torrential rain.

Perched Block. A large rock carried by a glacier and left far from its source when the ice melts.

RED GRANITE QUARTZ IN GABBRO PEGMATITE

Igneous rocks are formed when molten matter inside the earth is forced upwards and hardens on cooling.

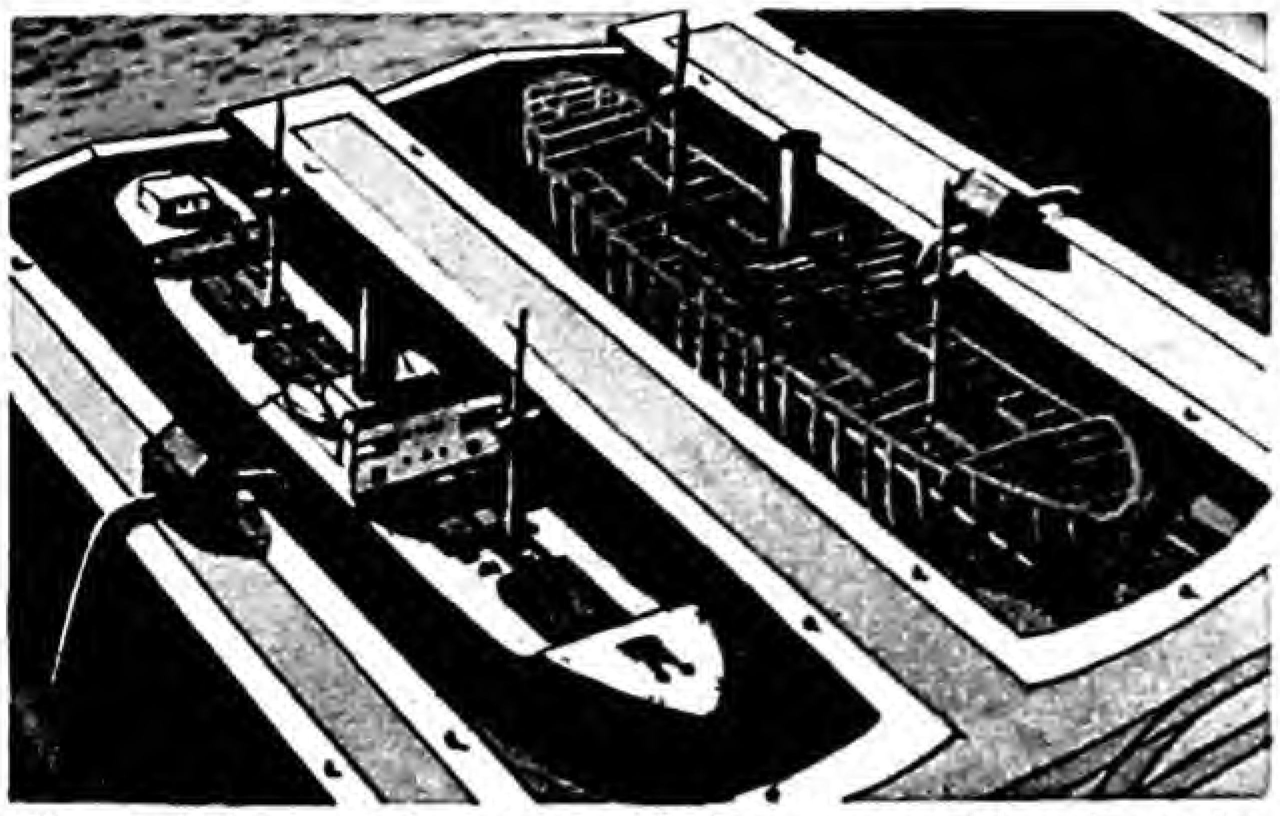
Cove. A small inlet enlarged by the sea breaking through a soft point in the mainly harder coastal rock. This is Lulworth Cove, Dorset.

Glaciated pavement. A polished and scratched rock floor formed under a glacier by the grinding action of stones held in the ice.

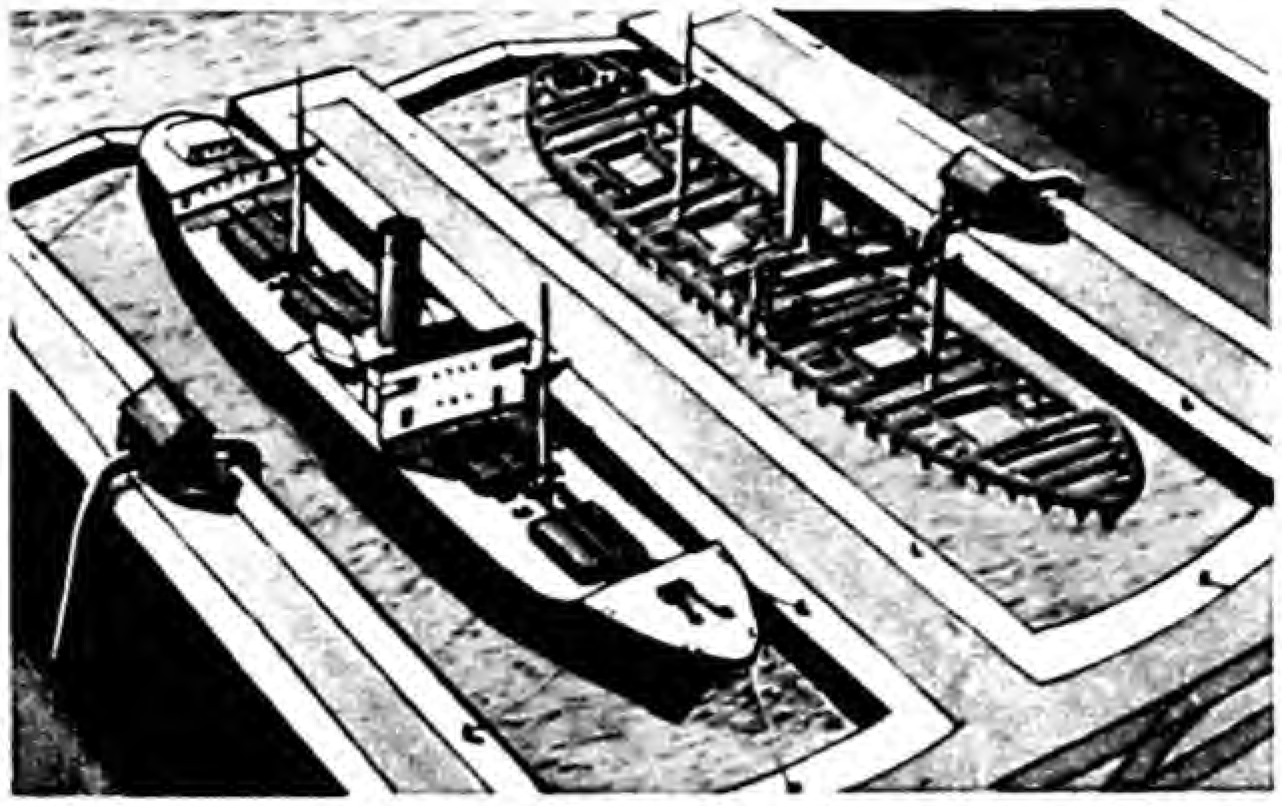
Abandoned waterfall. Diversion of stream leaves former waterfall as a cliff. The plunge pool with its boulders may remain at its foot.

Karst. Bare limestone free from soil and vegetation. Its surface is pitted and furrowed by rain which has dissolved it.

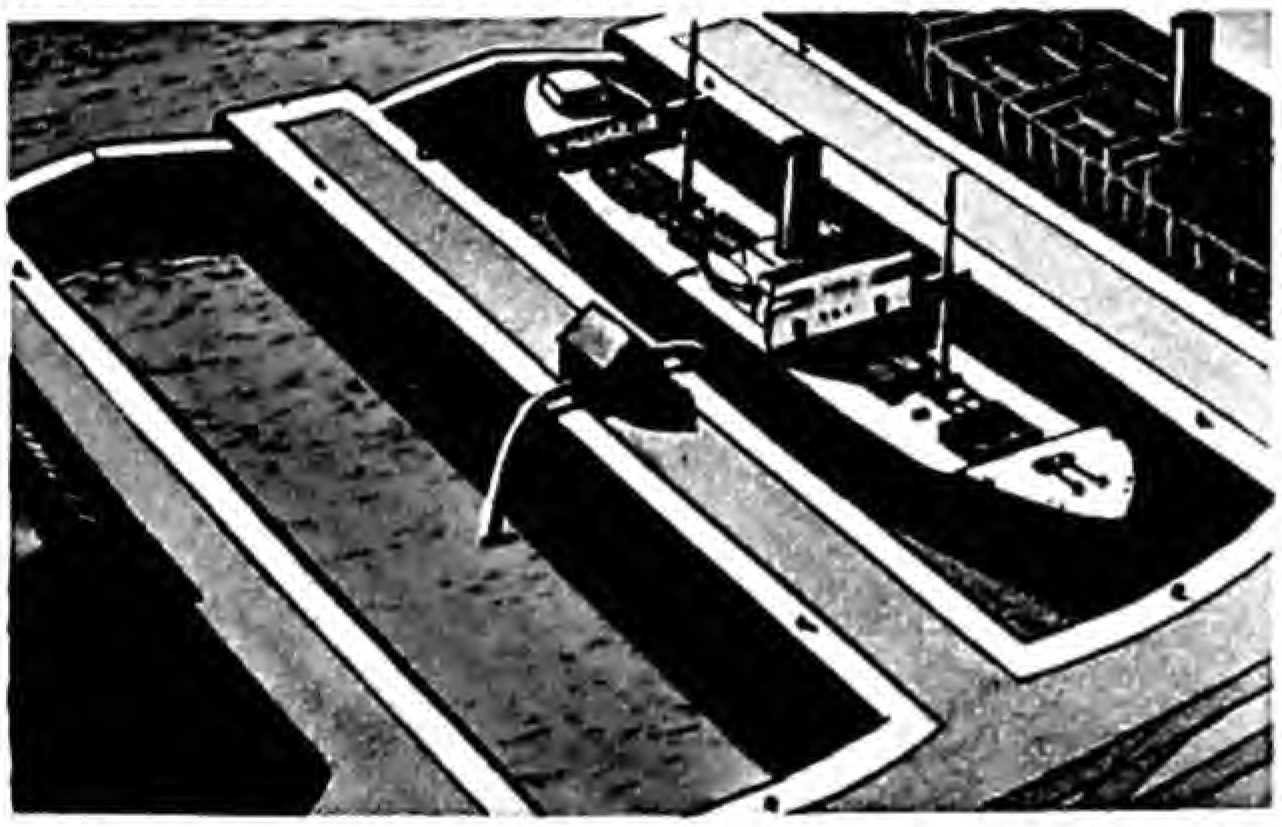
PRESSURES THAT MAKE SHIPS FLOAT



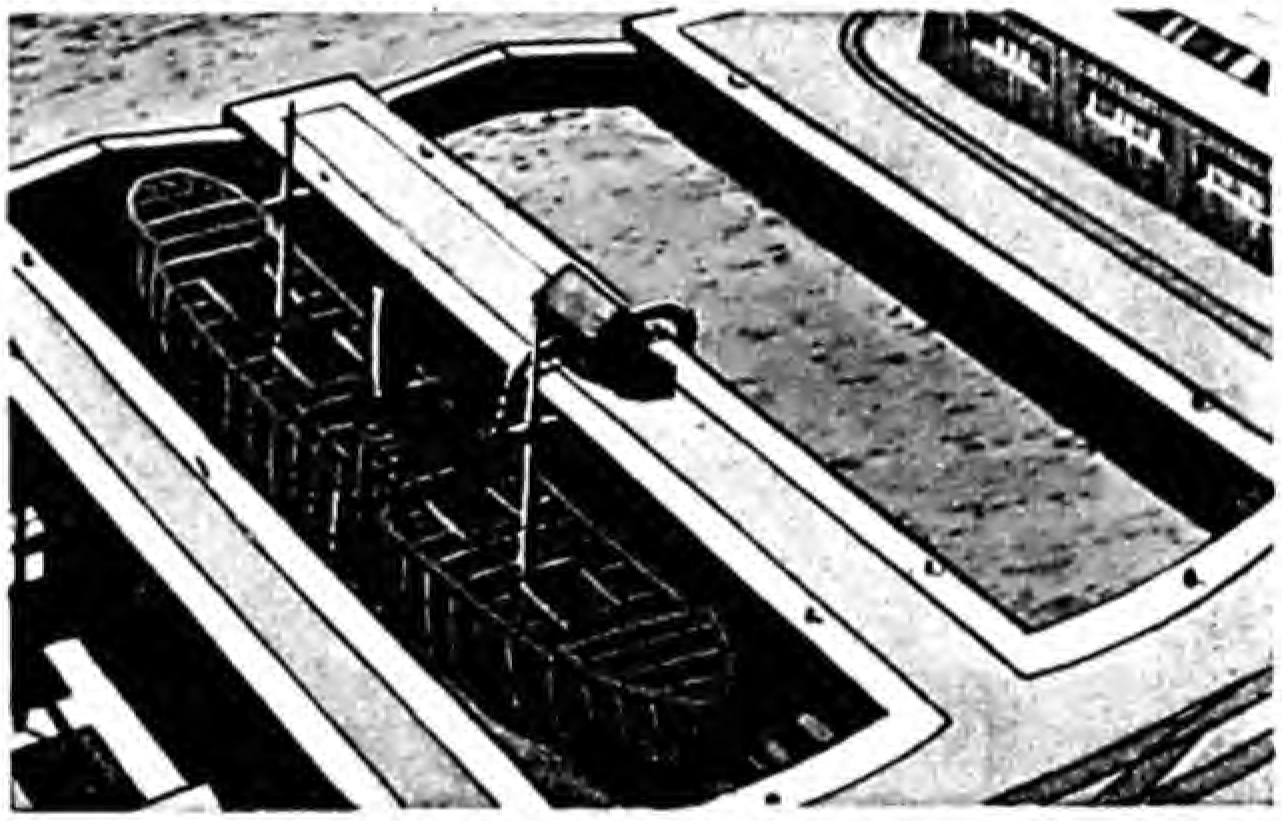
The weights of the parts of these two ships in twin graving docks are the same, but the plates of one have been made into a watertight hull, while the plates of the other are stacked at the end of the dock.



When water is pumped in, one ship floats while the other remains at the bottom. As they are both built of steel, why do they behave differently? Did both displace the same amount of water?



If the water is now pumped into the spare docks, you can see it was not the same amount. The finished ship being watertight could push aside a large quantity of water. The ship had displaced water equal to its total weight with only part of itself submerged.



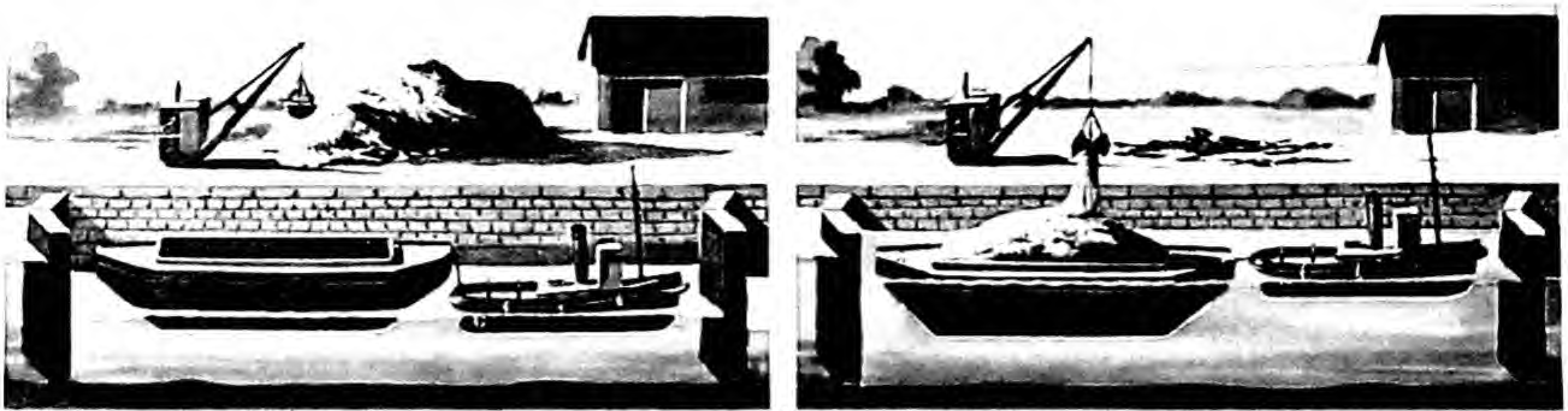
The unfinished ship weighed the same but took up only a small amount of space and therefore did not push aside much water. In fact it allowed room for a lot of extra water to get into the dock. It did not float because it could not displace its own weight of water.

One of the first scientists, Archimedes, a Greek who lived over 2,000 years ago, is supposed to have stepped into his bath when it was brimful, and to have been very interested when he noticed that his body pushed aside the water so that it overflowed. Most of us make the same discovery when we are very young by putting a spoon into a cup brimful of milk and seeing the milk spill over.

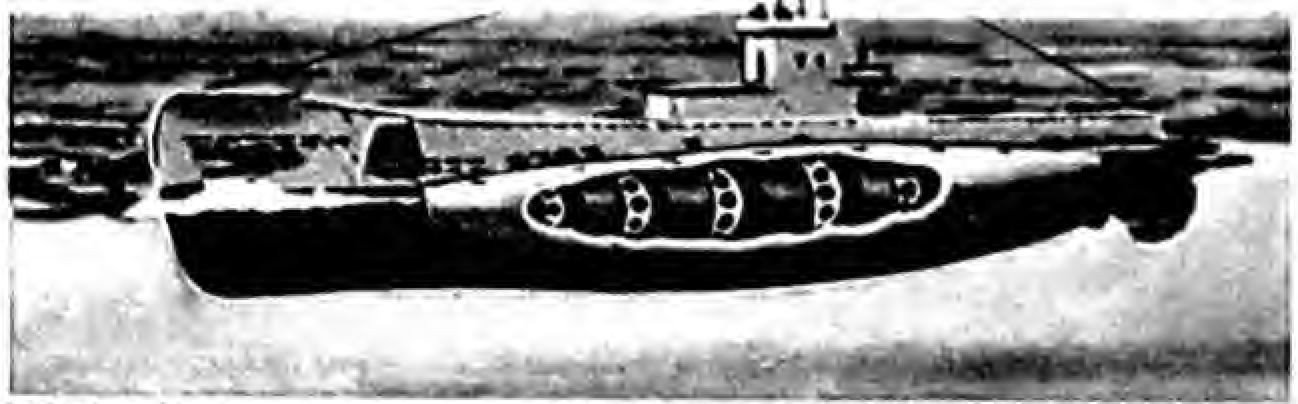
We also find we can dangle a chunk of iron on a piece of rope in water, and move it up and down quite easily, but when we pull it out of the water, the iron seems much heavier. Archimedes explained this. He said that an upward thrust acted on anything put into a liquid such as water, and that this thrust was equal to the weight of the liquid pushed aside.

Some materials, like pumice, take up so much space compared with their weight, that they only need to sink a little way into water to push aside their own weight of water. Thus they get enough upthrust to float when partly submerged.

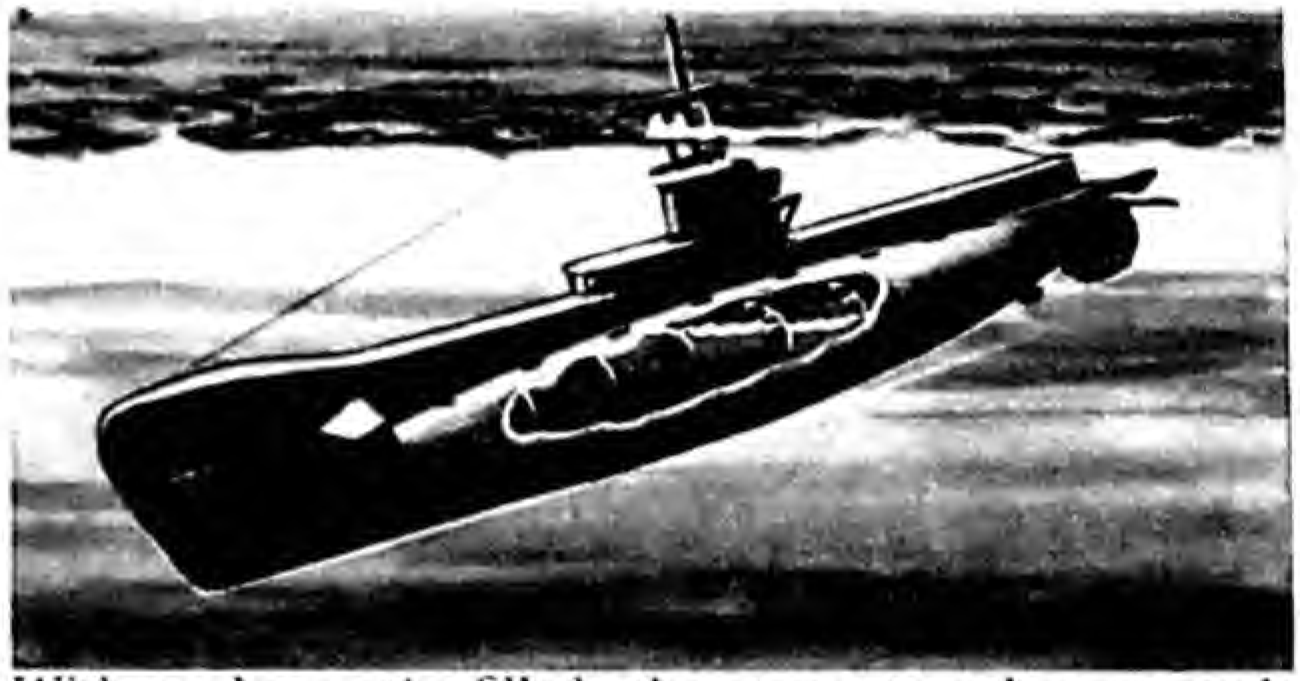
A piece of iron will not float, but the same piece of iron made into thin plates and shaped so that it will push aside a



This barge rides high in the water because only a small part of its hull pushes aside enough water to support its whole weight. When a heavy cargo is put aboard, the barge pushes aside a greater weight of water—enough to equal the weight of the barge and the cargo. The rise in the water level shows this. If so much cargo was put aboard that the barge sank it would be no use sending divers down to unload it. The boat would remain at the bottom because the water that had filled it had reduced its displacement to just the thickness of its hull plates.



With diving tanks empty, the submarine floats on the surface like a ship.



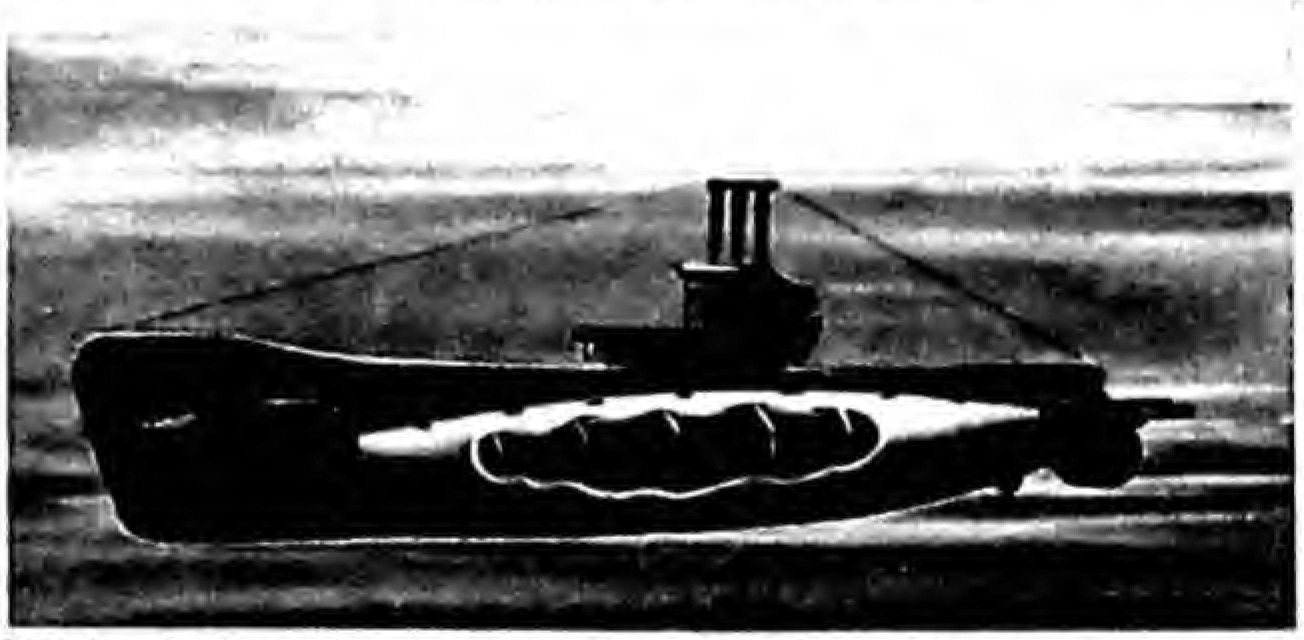
With tanks partly filled, she starts to submerge. As the tanks fill, she will keep on going down.

much bigger amount of water (like a buoy or a bottle) will float.

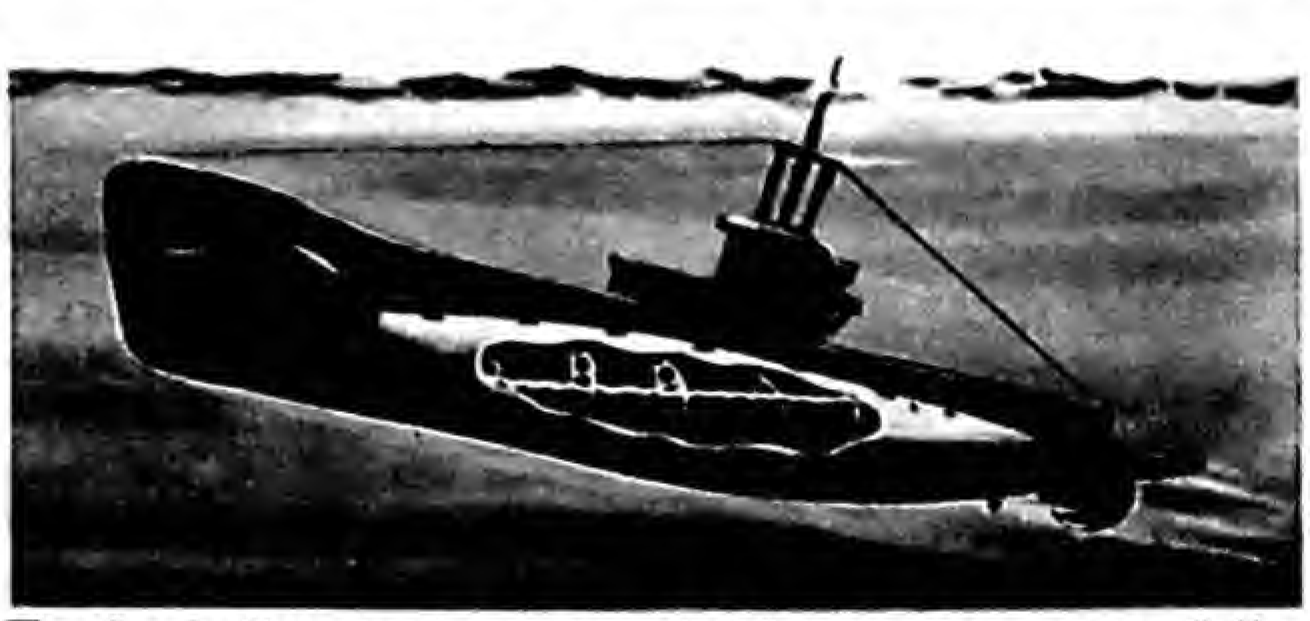
A boat is simply a specially constructed tank displacing enough water to float, even though it has to carry cargo as well as its own weight. Of course, if the hull leaks or water gets in through openings in the deck, the extra weight of water pouring in will eventually add up to more than the upthrust of displacement, and then the boat will sink.

A submarine is a boat with a watertight deck, in fact it is completely watertight. It can be purposely over-loaded to make it submerge below the surface. Once down under the sea, it can be unloaded (by emptying the water tanks) until it is again displacing more than its own weight when it will rise to the surface.

The water tanks are built round the air-



With full tanks, the craft does not displace enough weight of water to keep her on the surface, she dives.



To check dive, tanks are partly blown ; to surface, fully

A wooden ship floated high in the water because of her watertight hull. When holed, the air spaces in her wooden timbers still kept her afloat. After many years the timbers are waterlogged and the ship sinks.

tight part of the submarine fore and aft, and on each beam. The submarine commander can flood these by opening valves in their outer casings so that the sea pours in and the submarine dives. To come to the surface, he can push the water out again by means of pumps inside the submarine.

A log of timber contains tiny air-filled gaps between its fibres and because of this, it is comparatively bulky in proportion to its weight and is able to displace considerably more than its own weight in water. When ships were built of wood, once they were holed by collision or some other mishap, the water coming into the hull, added to the weight of the cargo was usually sufficient to send them to the bottom. If there was no cargo, the sea filling up the hull did no more than make the ship ride lower in the water ; sufficient buoyancy remaining in the timbers to keep the ship afloat. In course of time this buoyancy would be lost because the water gradually seeped in between the fibres of the wood, replacing the air held in these cavities, with the result that the wood no longer displaced more than its own weight of water. It could easily take fifty years or more for the wreck of a wooden ship to become waterlogged and many times sailors have met ancient wrecks still floating far out to sea.

Some kinds of timber such as ironwood and ebony will not float at all. This is because the fibres in them are packed so closely that there are not sufficient air spaces to give them buoyancy.

The buoyancy of a kapok life-jacket is due to the air-spaces in it. Air too, keeps the air-inflated raft and the " Mae West " jacket afloat. Although the lifeboat has shipped water she does not sink because of the air in her buoyancy tanks which, because they are filled with air, are displacing more than the lifeboat's weight of water. The water it has shipped does not count as weight, only as lack of displacement.

Salvage and Wreck Removal

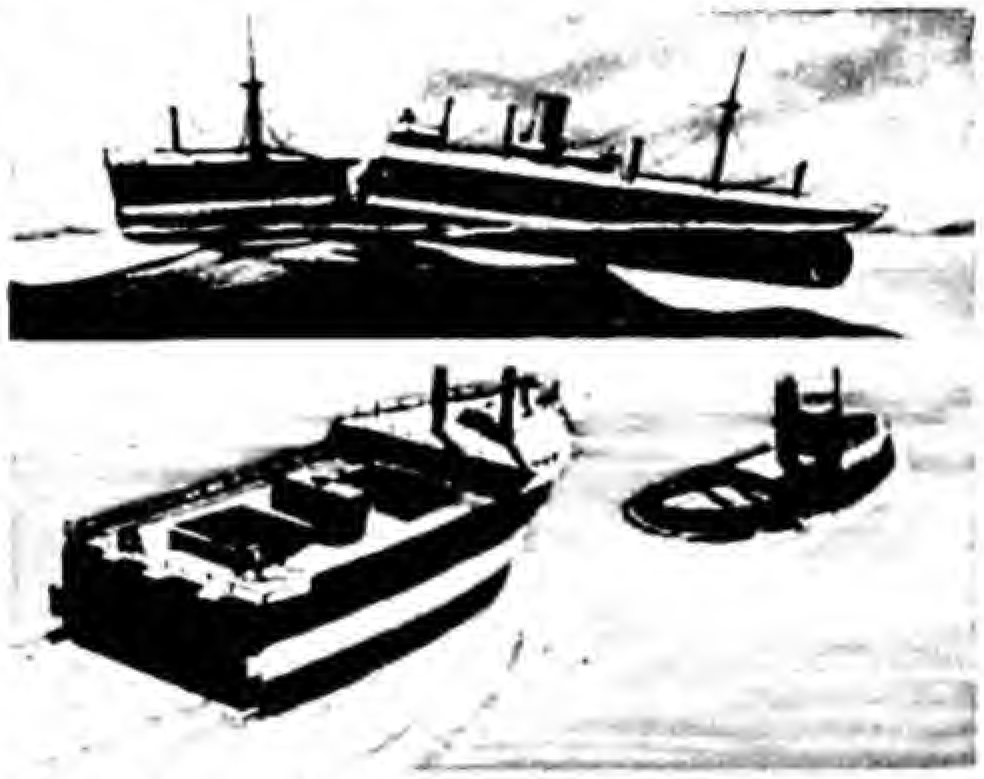
Salvaging wrecked ships is tackled in many ways. Every salvage operation presents a separate problem because the size of the wreck, its depth, position, the extent of the damage and the nature of the sea bed is different in every case.

The salvor's most potent ally is air. Air means buoyancy. It can make the total weight of the wreck less than the total weight of the volume of water it displaces, so that the displaced water will exert an upward force that will give the vessel buoyancy.

Before this is done, divers make the hull water-tight by patching all holes and strengthening decks.

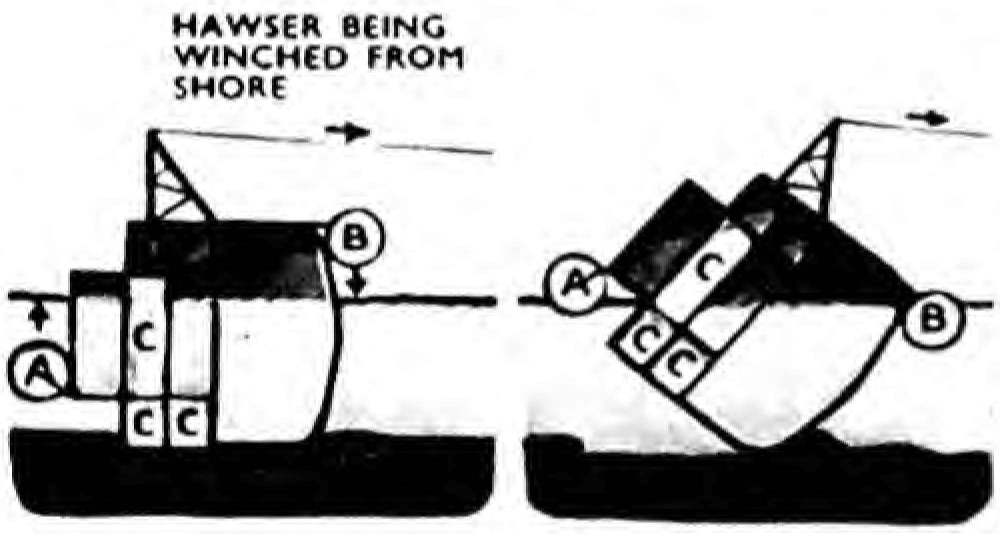
One simple method of adding buoyancy sometimes used when a small ship is

Raising a submarine sunk in shallow water. Buoyancy is given by four camels secured to the flooded forward end of the submarine. When air is injected into the camels, the bows will be lifted.

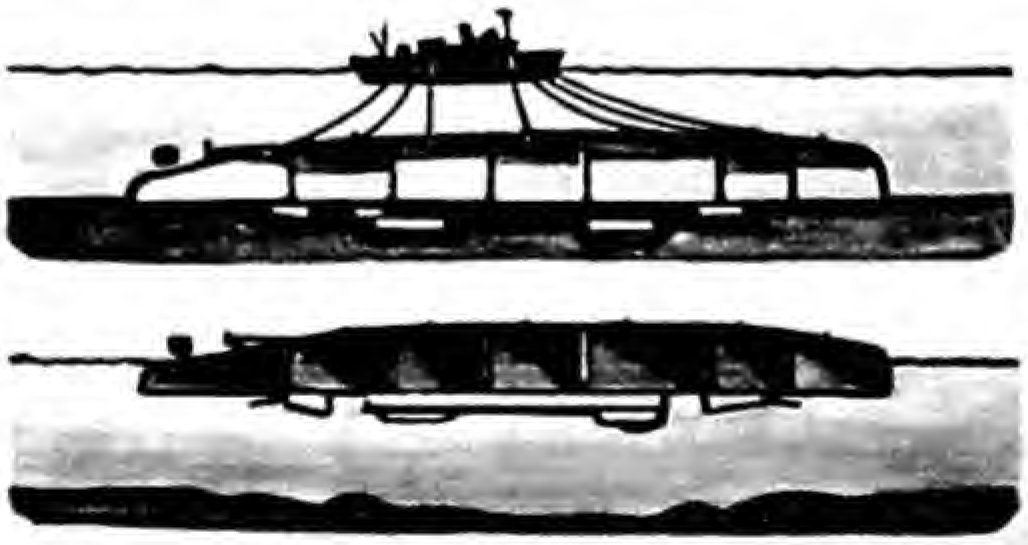


This ship rode over a sea wall and broke her back. Divers cut off the forepart and sealed it so it would float.

A new afterpart is built and the two portions are floated into the dock and joined together.



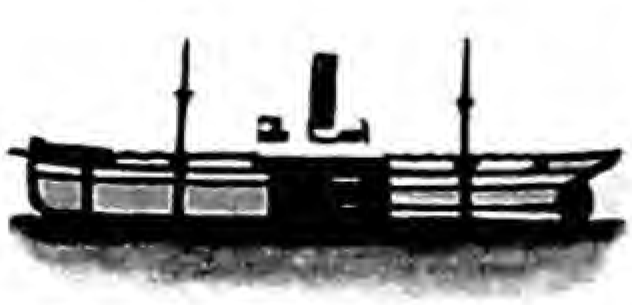
Righting a ship by buoyancy and counterweighting. (A) Air-filled camels (B) Water-filled camels. (C) Compressed air.



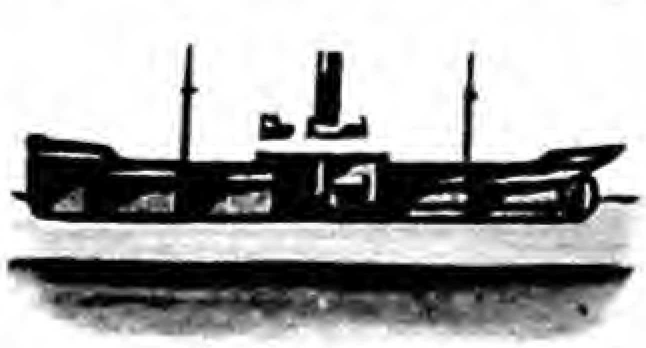
Raising scuttled German warships at Scapa Flow (Top) Compressed air pumped into hull. (Below) Ship raised, bottom up.

Diver fixing steel patch to submerged wreck before she is raised.

This ship is sagging—her midship section is flooded with fore and aft sections afloat.



To avoid the danger of breaking her back, she is flooded and sunk to the bottom.

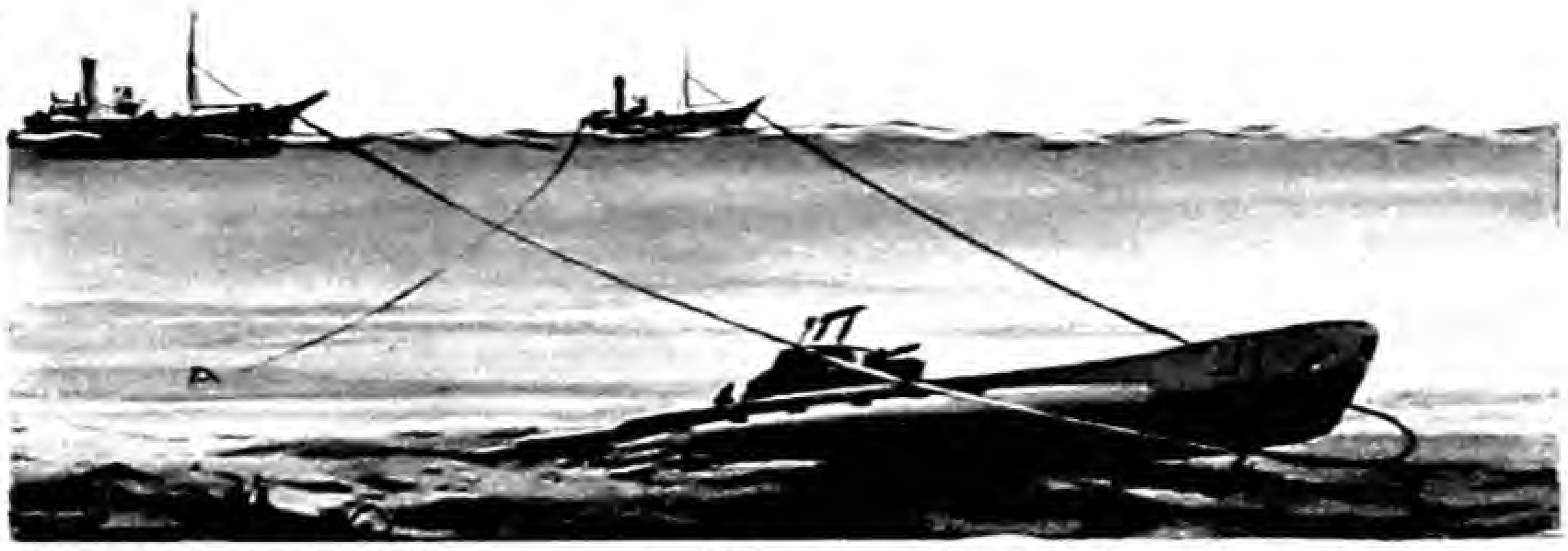


Patched amidships, and with water pumped out of all compartments, she is refloated.

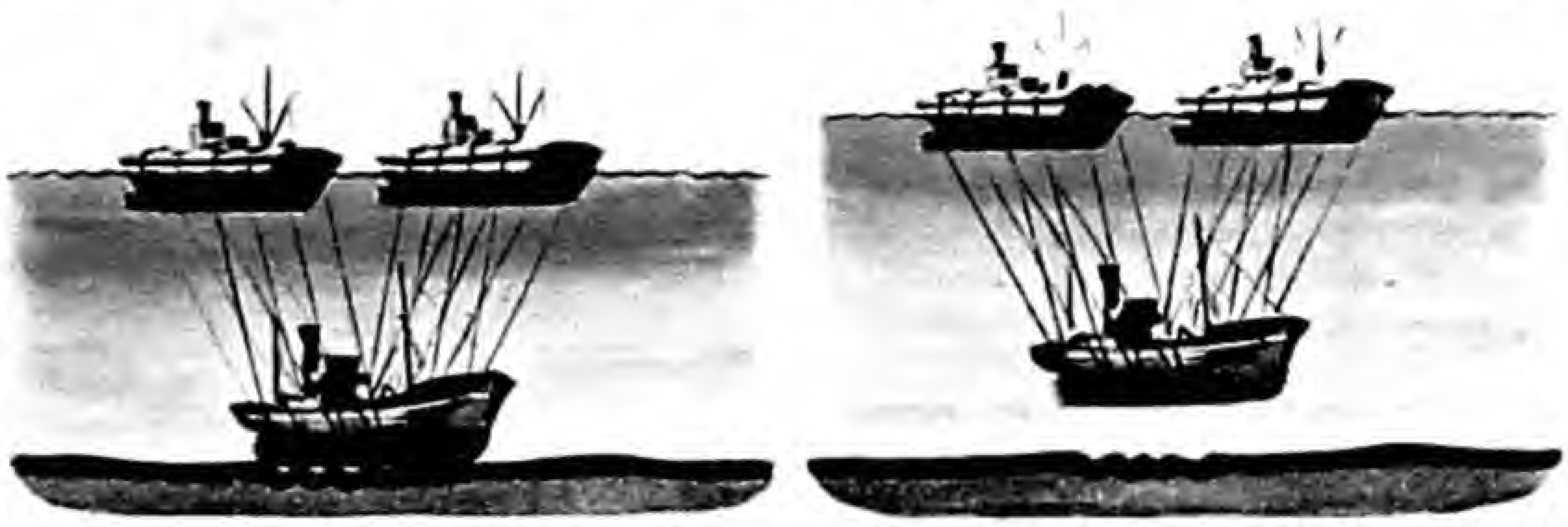
Hogging—the reverse of sagging, but equally dangerous. Ship aground on a bank or rock.

sunk in shallow water, is to send down watertight barrels to be placed in the hold by divers. Air is thus placed piecemeal into the vessel until she receives sufficient buoyancy to rise. Another device is to place rubber and canvas air bags in the holds or to lash them to her sides and then to fill them with air.

A more usual course is the use of pontoons or camels. Camels are watertight cylinders of timber or steel fitted with inlet and escape valves for the entry or ejection of water and with hawse-pipes or eyes through which cables can be passed for securing to sunken vessels.



A cable is trawled between two lifting vessels until it catches the bows of a wrecked submarine. The lifting vessels then alternately haul the sweep to give a sawing motion so that the wire cuts into the mud under the wreck.



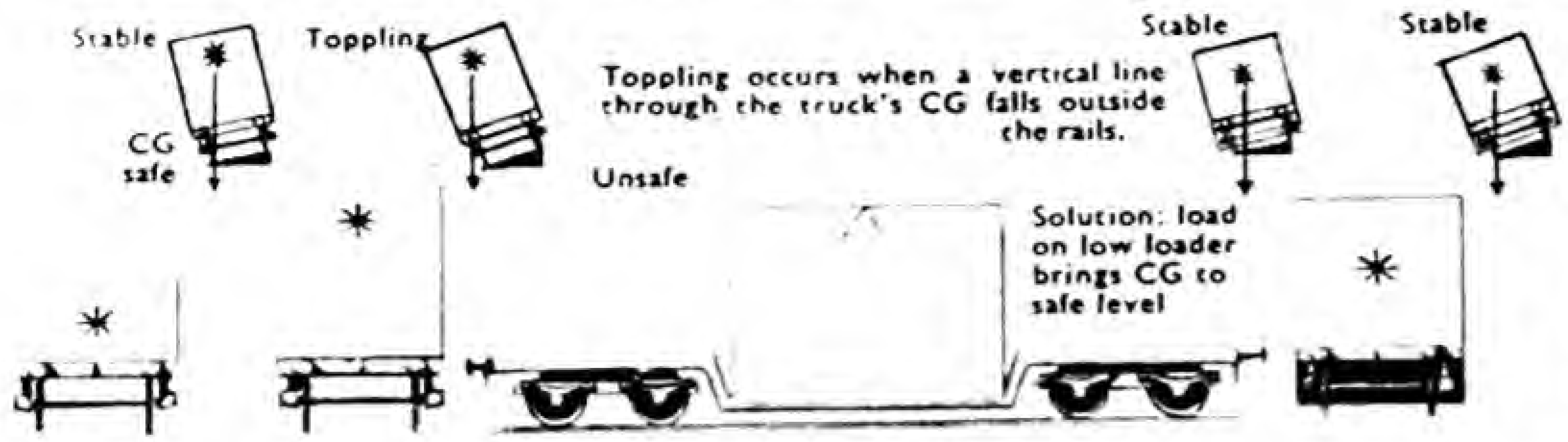
Steel wire ropes are passed under a wreck, and attached to lifting vessels. As the tide rises, the wrecked ship is lifted from the bottom and is then taken to shallow water.

A floating dock is a huge trough with a hollow pontoon as its deck. When valves are opened, water enters and the dock is partly submerged. A damaged ship is towed into the dock by tugs. When the pontoon is pumped out, buoyancy of the dock supports its weight and that of the ship.

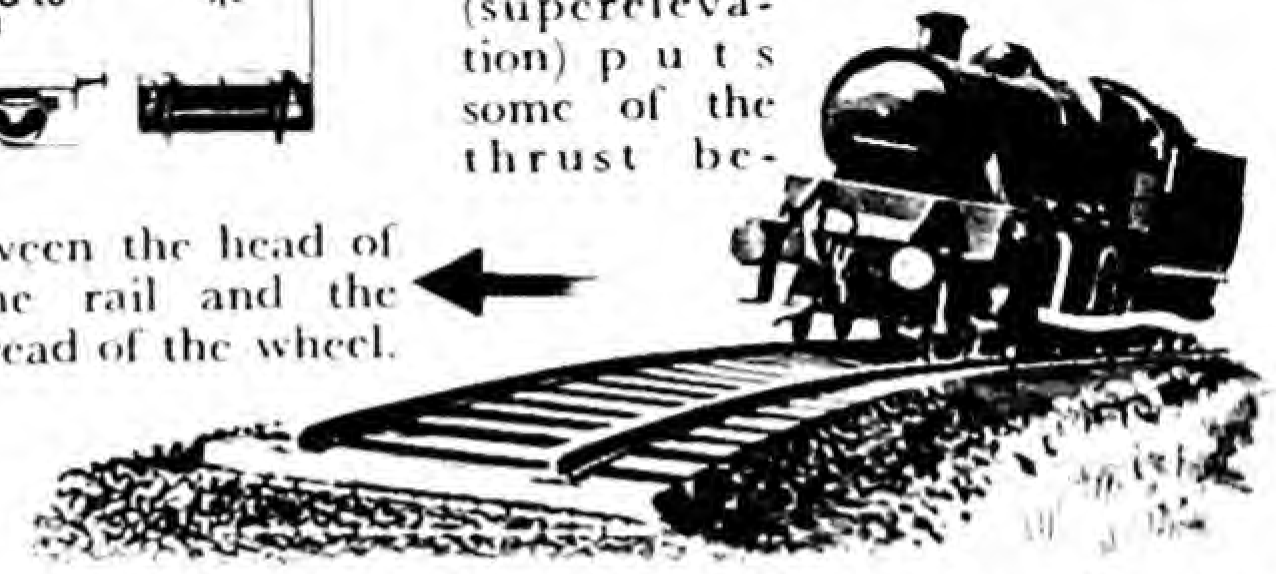
Driven ashore in a storm, this ship is high and dry on a sandy beach. A channel is cut in the sand by bulldozers to bring water to refloat her. Another method would be to sluice the sand away with hoses. A boat takes a kedge anchor out to sea. By hauling on the cable to the anchor, the vessel winches herself into the sea. A tug assists.

The Laws LOCOMOTIVE ENGINEERS Use

Railway engineers are very familiar with the laws of motion as studied in mechanics—they have to be. Most of locomotive design and railway operation is based on them.

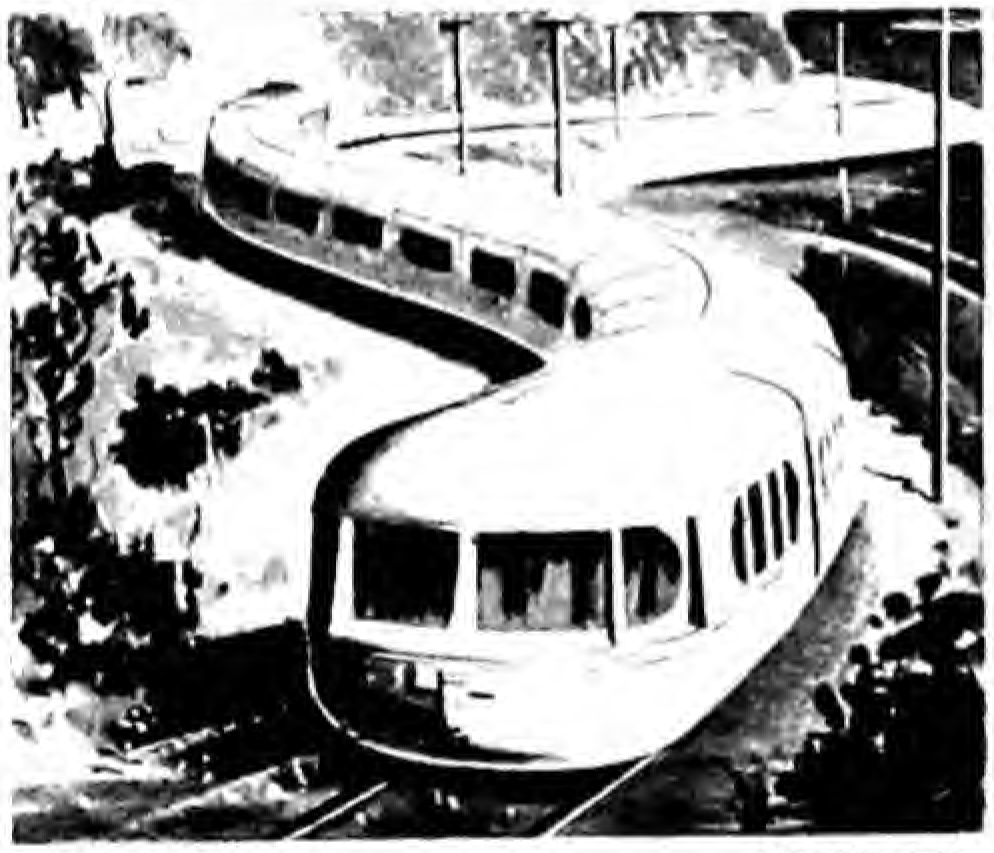


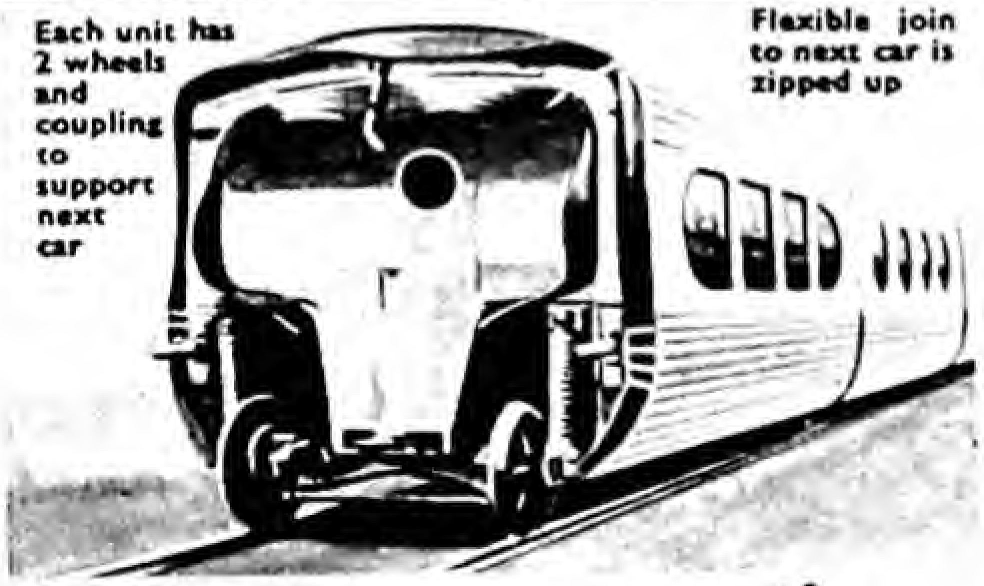
SUPERELEVATION. A loco rounding a bend tends to continue in a straight line. The side of the rail pushing against the wheel flange applies a sideways force. Banking the outer rail (superelevation) puts some of the thrust between the head of the rail and the tread of the wheel.



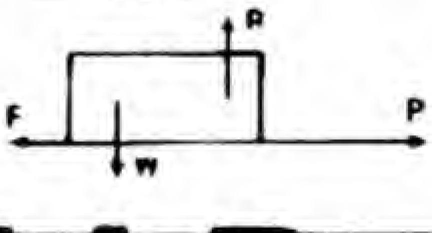
Centre of Gravity

Toppling occurs when a vertical line through the truck's CG falls *outside* the rails. The Spanish Talgo has a low CG allowing high speeds on a curved track.

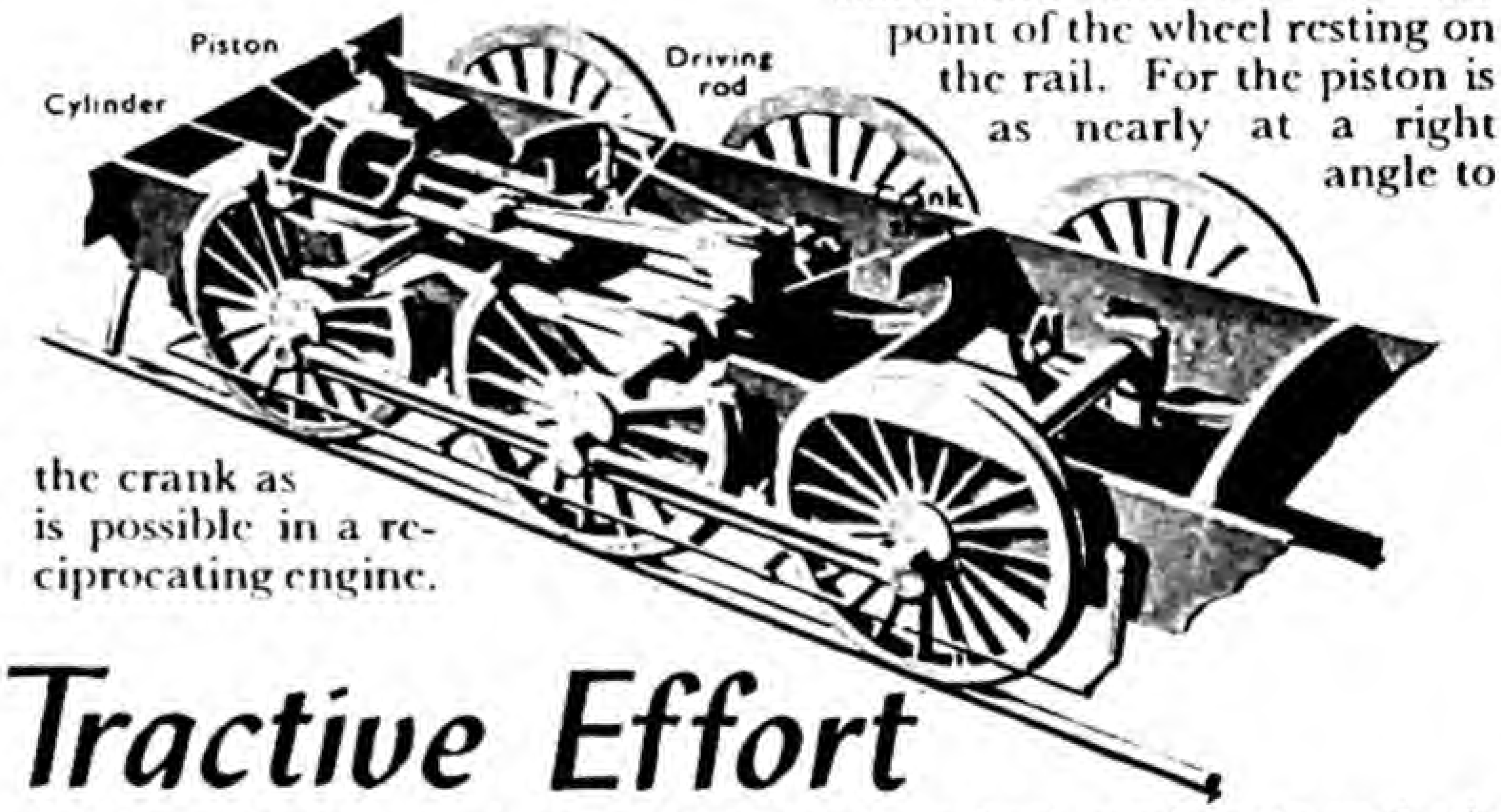




F = friction.
P = thrust of wheel.
W = weight or axle loading.
R = natural resistance upwards of the rail.

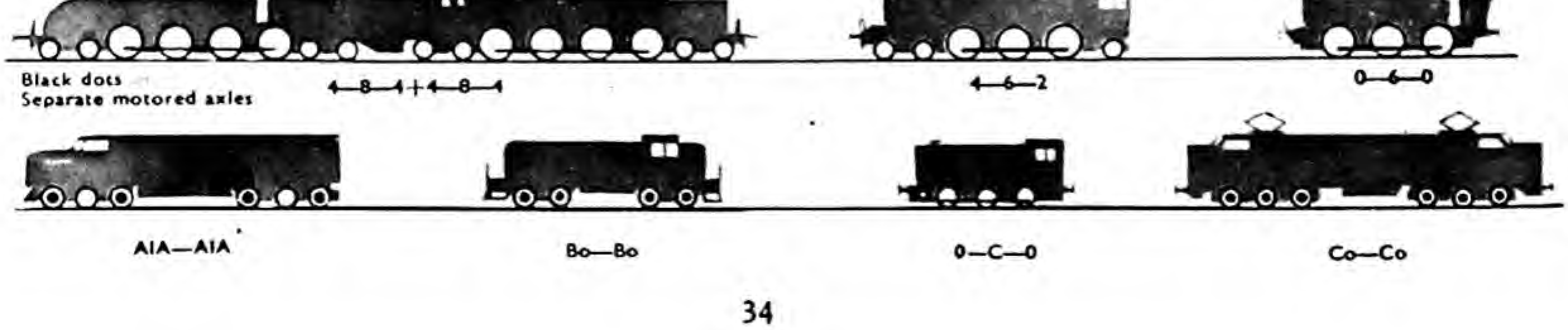


The piston rod of the engine cylinder shown here is at this moment delivering its greatest effort to the crankshaft and therefore to the point of the wheel resting on the rail. For the piston is as nearly at a right angle to the crank as is possible in a reciprocating engine.



Tractive Effort

Without friction the locomotive's driving wheel would spin uselessly. The thrust of the wheel must be equalled by the amount of friction between it and the rail if it is to move along without spinning. The friction will be increased if the downward pressure on the rail is increased. As a result locomotives are designed so that the axle loading of the driving wheels is weighty enough to provide friction that equals their power, and trailing bogies loaded as little as possible. The possibility in diesel and electric locomotives of driving axles separately means the tractive effort can be increased by dispersing the driving wheels so each pair is given maximum loading, and therefore have maximum friction so they grip the rails to the best advantage. *See also* FORCES AND MECHANICAL LAWS



Axle Bearings

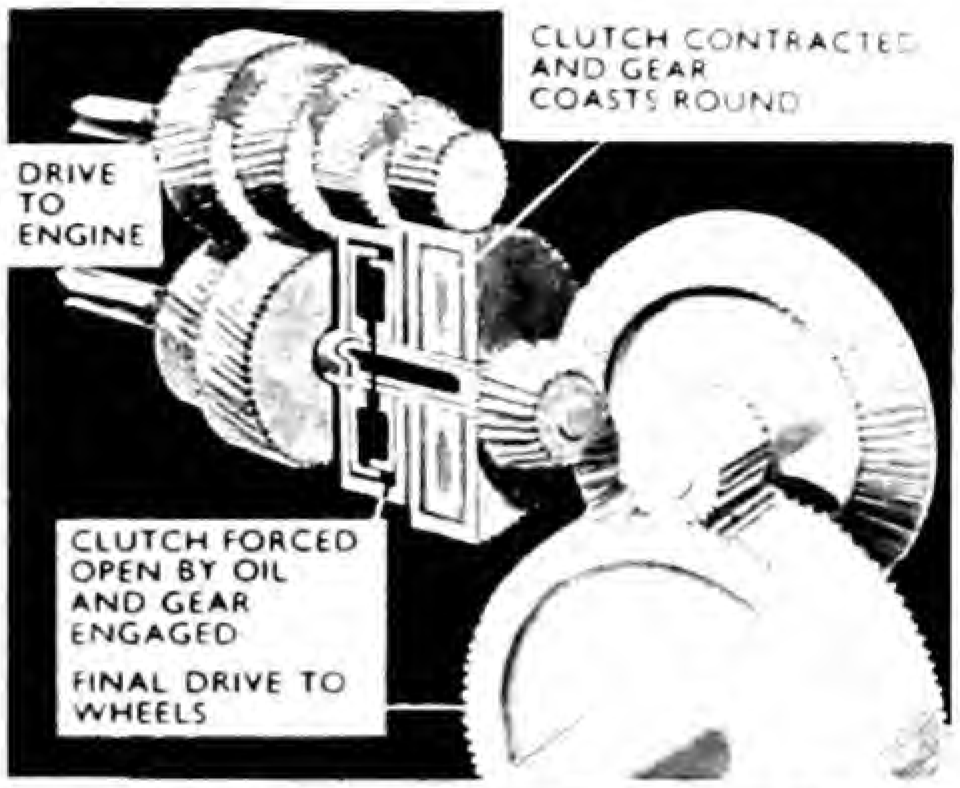
A wheel is more efficient than a sledge (as long of course as there is enough of it to grip) for the point of contact of a wheel is momentarily at rest and no work has to be done to *overcome* friction.

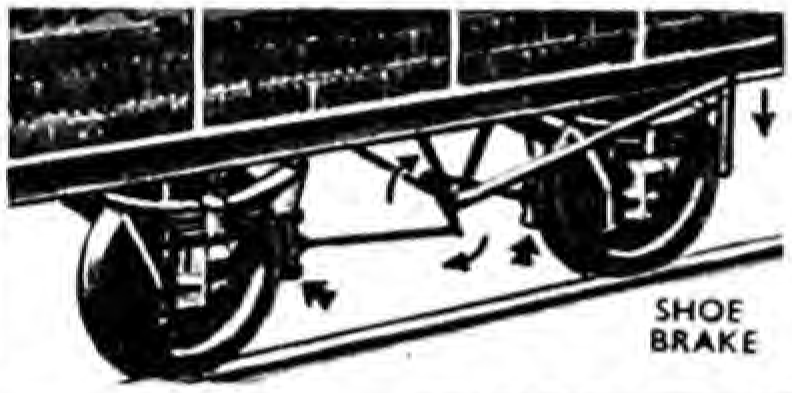
Axle in axlebox slides round in bearing, friction slightly reduced by grease.

Ball bearings roll round reducing friction to little more than on wheel.

Roller bearings distribute weight better than ball bearings so reducing wear.

All brakes are friction making devices. Shoe brakes grip on the edge of the railway wheel. Disc brakes are infinitely more powerful for their frictional contact is with the whole twisting faces of the discs. A clutch is really a two-ended brake that can connect two revolving surfaces.



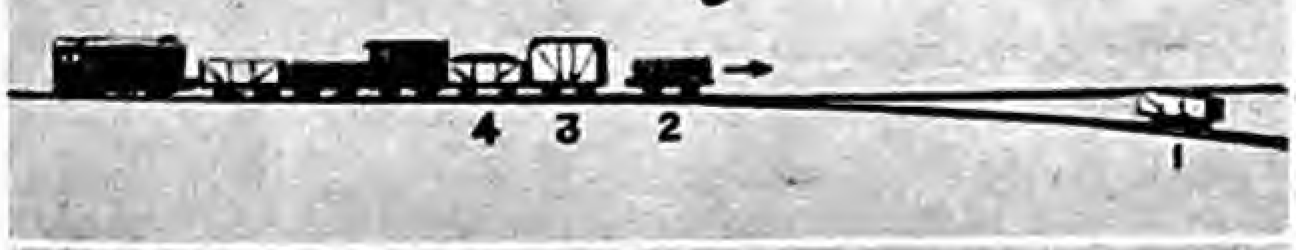


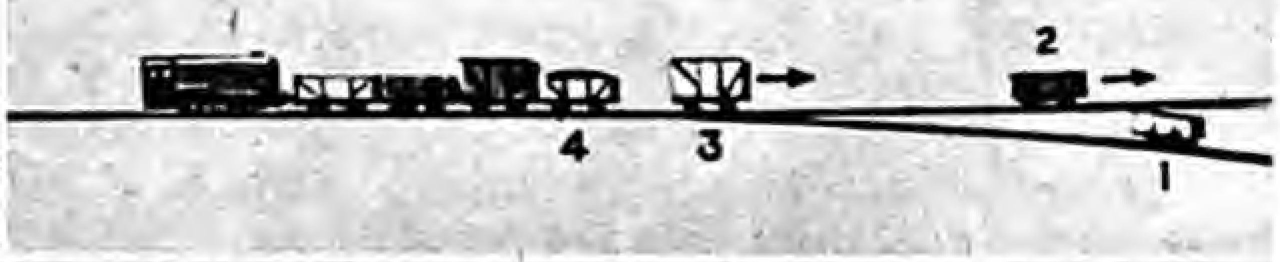
Inertia

Where single track working with loop lines is common it is a problem getting the train in the loop started again. To overcome its inertia once it has stopped the locomotive uses up a great deal of fuel. Longer by-pass loops have now been laid by some U.S. railroads in which the switched down train can keep moving while the up train goes by on the main track. A truck pushed to the crest of the 'hump' in marshalling yard (right) has a great deal of potential energy stored up—its potential of running down the slope. It will use it up running along the flat.

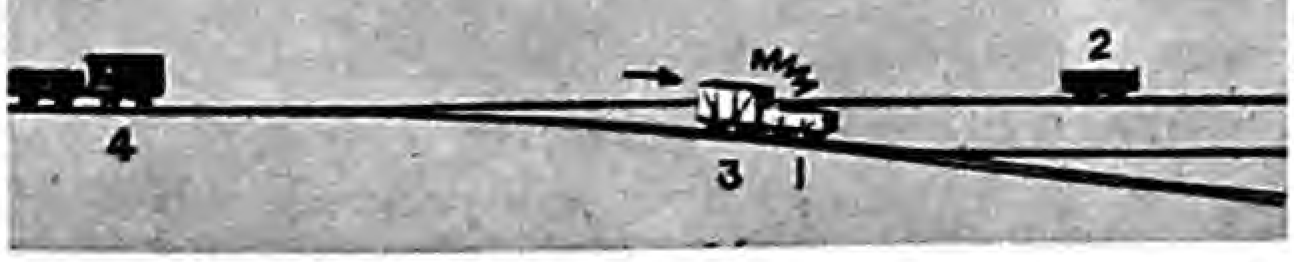
The Art of Shunting

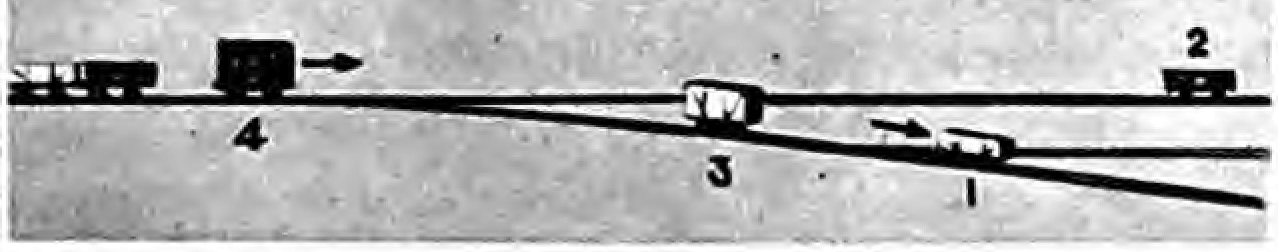
The shunting engine by pushing trucks gives them energy. They use up some of this energy running along the sidings. In fact a truck often uses the last of its energy trying to change the shape of the buffers. Here truck 3 bangs

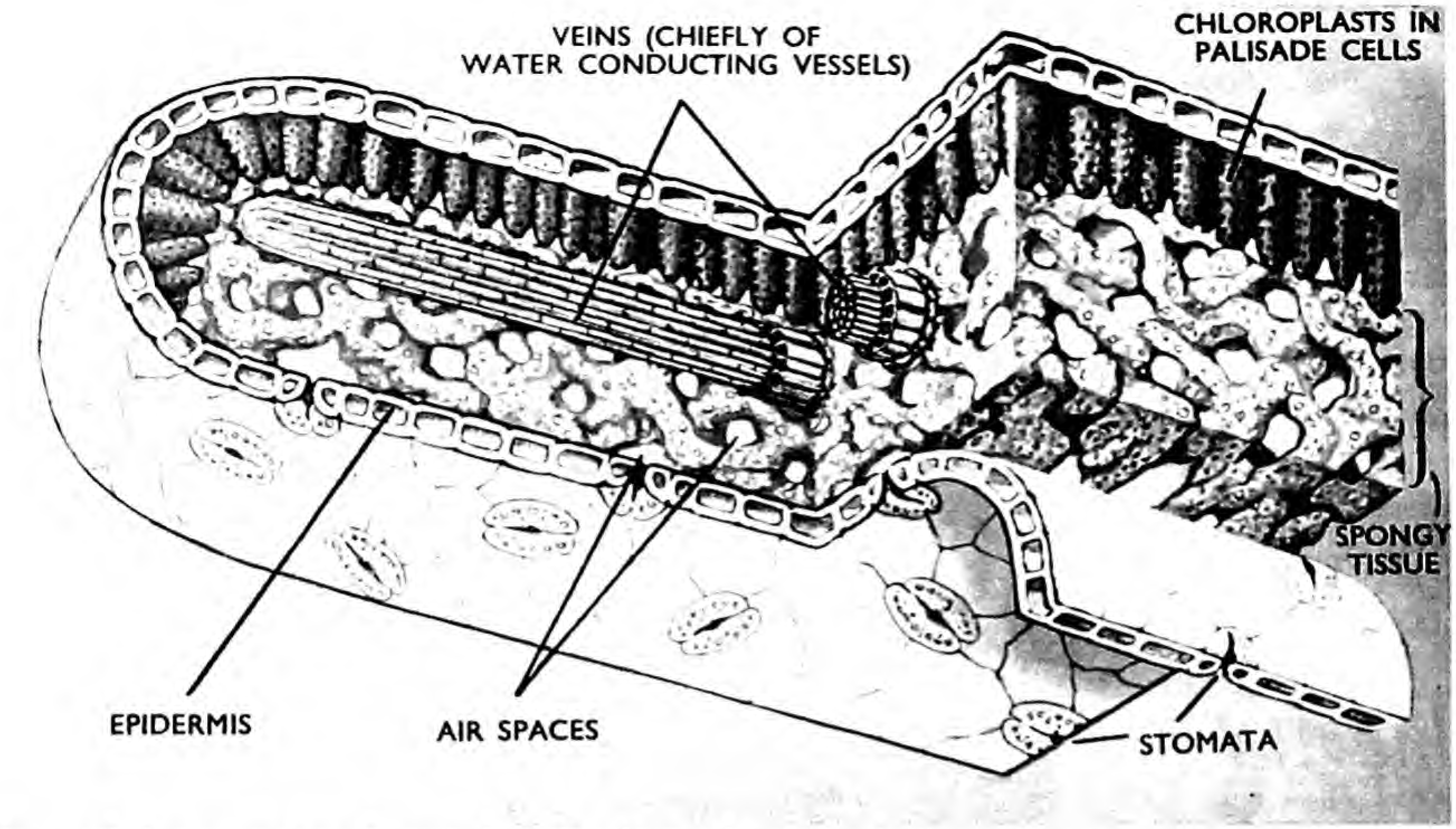




into truck 1 which has come to rest. It converts its energy into Kinetic energy, that is work energy, that sends the stationary truck rolling though the second truck itself comes to a stop because it has no energy now it has transferred it all to the other truck.





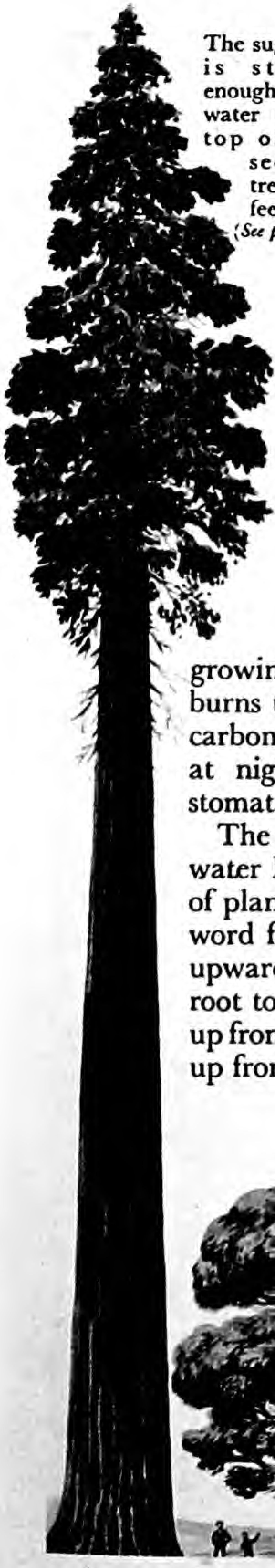


A magnified cut-away view of a green leaf. The skin (epidermis) is colourless and transparent to light. Chlorophyll in the inner cells makes the leaf appear green. The stomata (or mouths) can open and close.

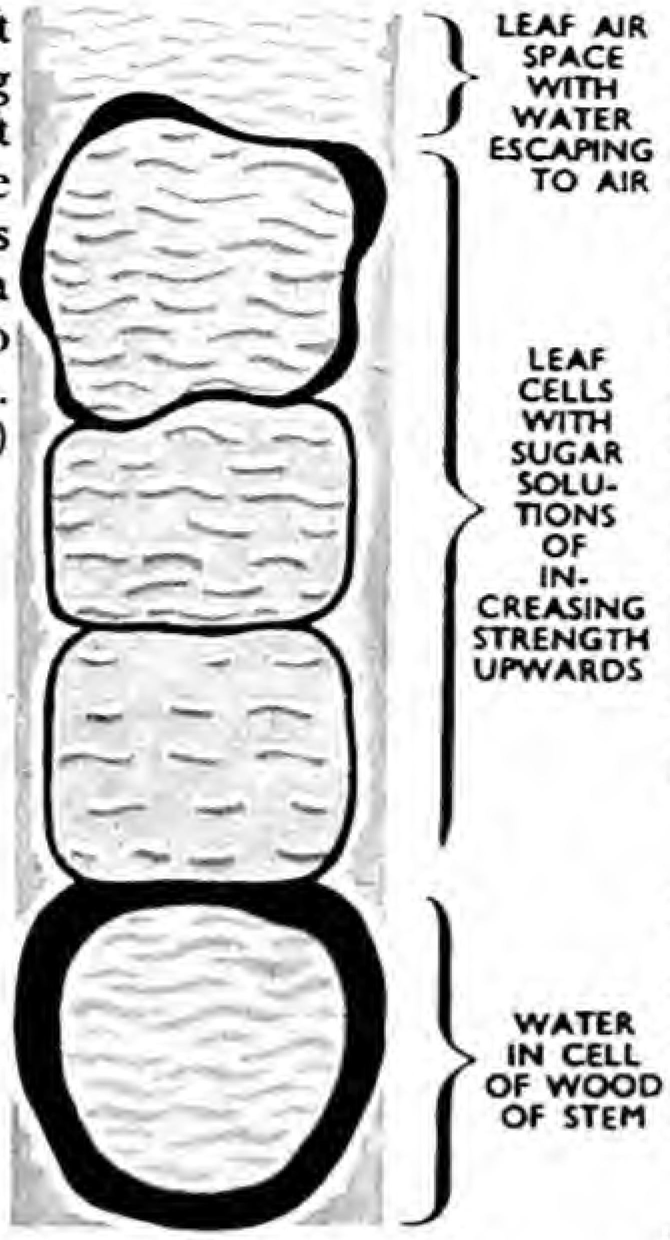
THE DAILY LIFE OF A PLANT

When day becomes night the balance of the living processes going on in the leaves of a plant is changed. While the sun's rays (even if their strength is lessened by the clouds) are shining onto the leaves little openings in the skin (epidermis) of the leaf, called *stomata*, open and let carbon dioxide from the air enter the leaf. The gas gets into the " factory cells " (called *palisade cells* because they are arranged rather like a fence) together with water (a compound of hydrogen and oxygen) brought up from the soil by the roots. When the " factory cells " are working they join the carbon, hydrogen and oxygen into starch (carbohydrates). Sunlight entering through the transparent roof (the skin of the leaf) provides the energy which works the factory cell. The benches where the job is done are the granules called chloroplasts. These contain a green substance, *chlorophyll* which transfers the energy of the sunlight into the process of starch making.

All day long the leaves are busy making starch and passing out through the *stomata* the oxygen formed during the process. But when the sun sets the life of the plant changes. The cell factories can no longer work without the sun shining onto their chlorophyll. The " night shift " has a different job to do. The tiny grains of starch are converted into sugar which dissolves in water and travels away through the veins. It can pass to every part of the plant but moves chiefly to regions where sugar is being used up. Some of it is burned up to set free energy for doing such jobs as making new cells in the busily

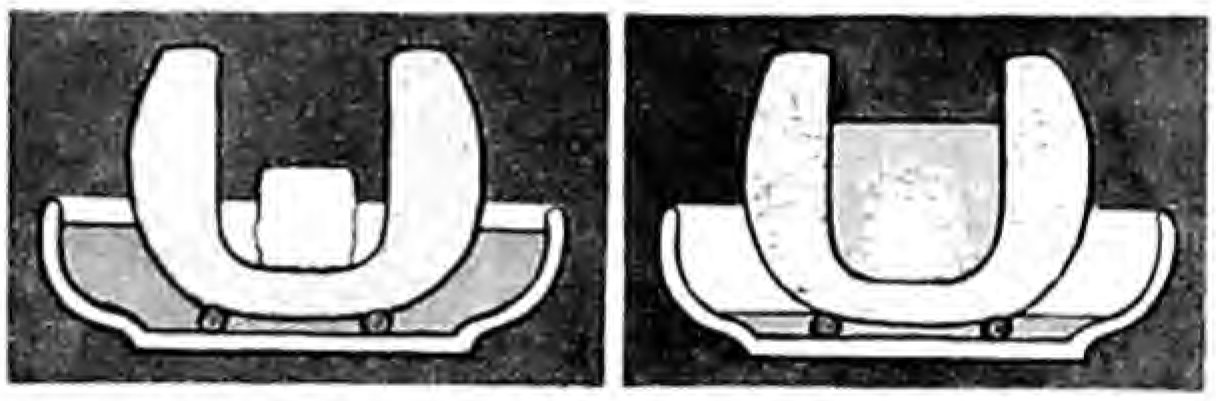


The sugar lift is strong enough to lift water to the top of this sequoia tree, 200 feet high. (*See page* 67.)



During the day the heat of the sun evaporates from the leaves some of the water of their cells. This makes the sugar solution in the leaf cells stronger and the stronger it is the more it pulls the water towards it from the cells below them. These in their turn are left with an increase in sugar concentration since they have lost water to the cells above them and this suction continues right down to the root hairs.

The shoots of a plant always grow towards the light. Botanists have discovered that the speed of growth is controlled by hormones formed in the tips of the new shoots. But strangely enough

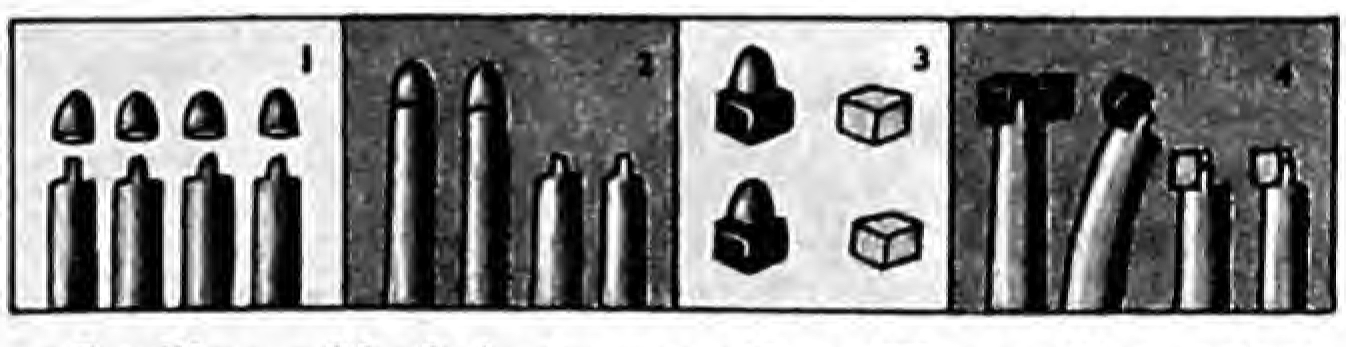


To show that the sugar lift actually works, hollow out a potato and place it on two match sticks in a saucer of water. Put a lump of sugar in the hollow. After a few hours you will find that the sugar has drawn the water up through the potato to fill the hollow.

light actually *decreases* the production of these hormones. Thus it is on the darker side that a shoot has the most hormones. So on the dark side the growth is faster and as the light side is growing less, the shoot is pushed over towards the light, and " grows towards the sun ". It is just like being on the inside lane of a running track.

growing parts of the plant. As it burns the sugar turns back into carbon dioxide and water which, at night, escape through the stomata. (*See page* 67.)

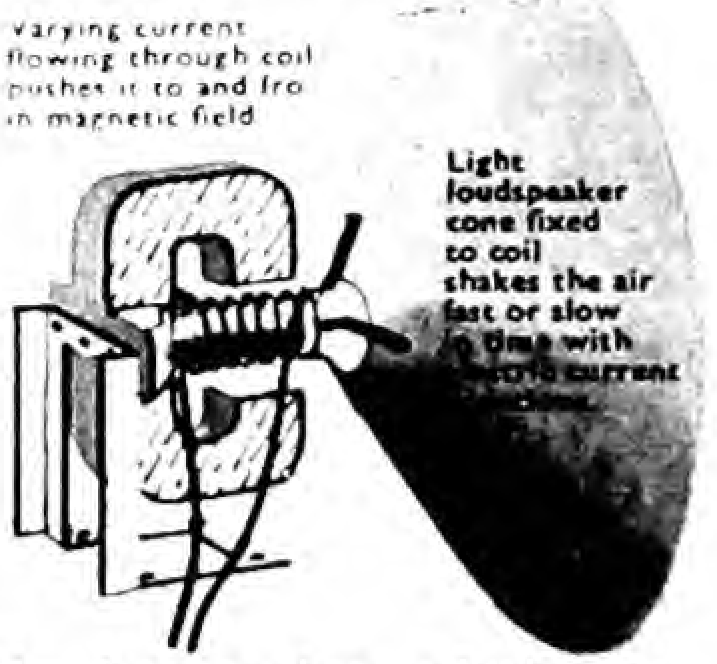
The use of sugar in the plant's water lift is one of the wonders of plant life. " Lift " is a good word for the way water moves upwards through the plant from root to leaf as it is not pumped up from below but rather drawn up from above.



1. Seedlings with their tips cut off. 2. The seedlings which have their tips, and hormones, replaced continue to grow, the others do not. 3. The two blocks of jelly take in hormones from the seedling tips. The other two get no hormones. 4. Jelly blocks with hormones make the beheaded seedlings grow again on both sides or only one. Plain jelly has no effect.

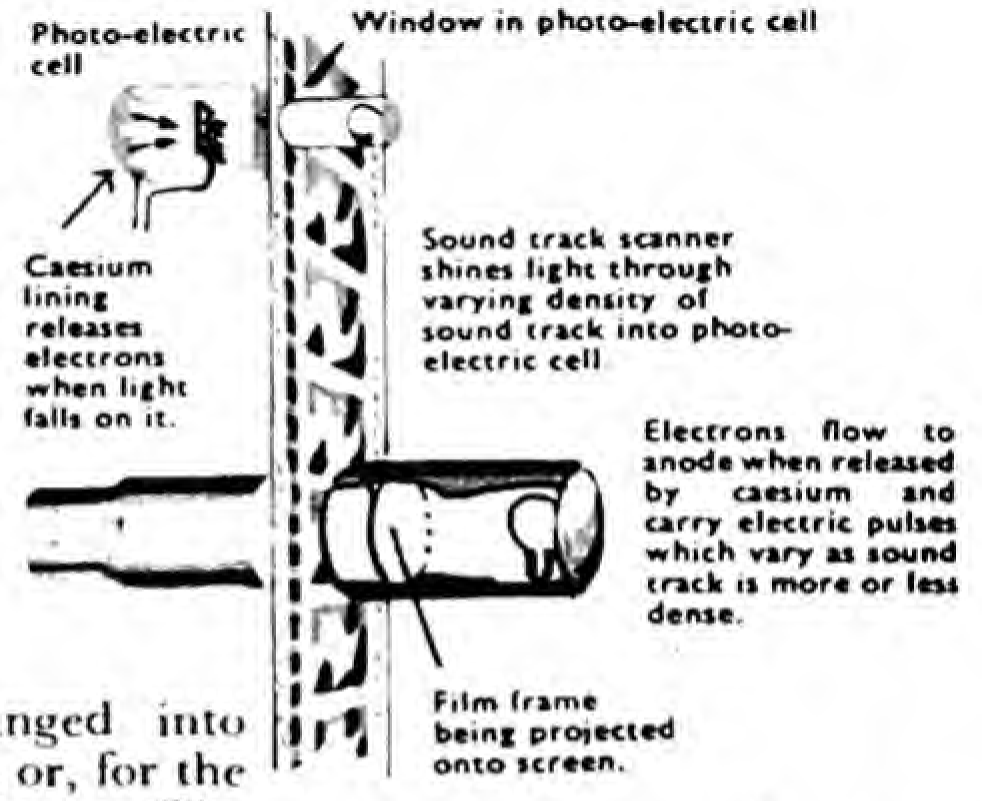
OAK TREE

THE SHAKING OF THE AIR

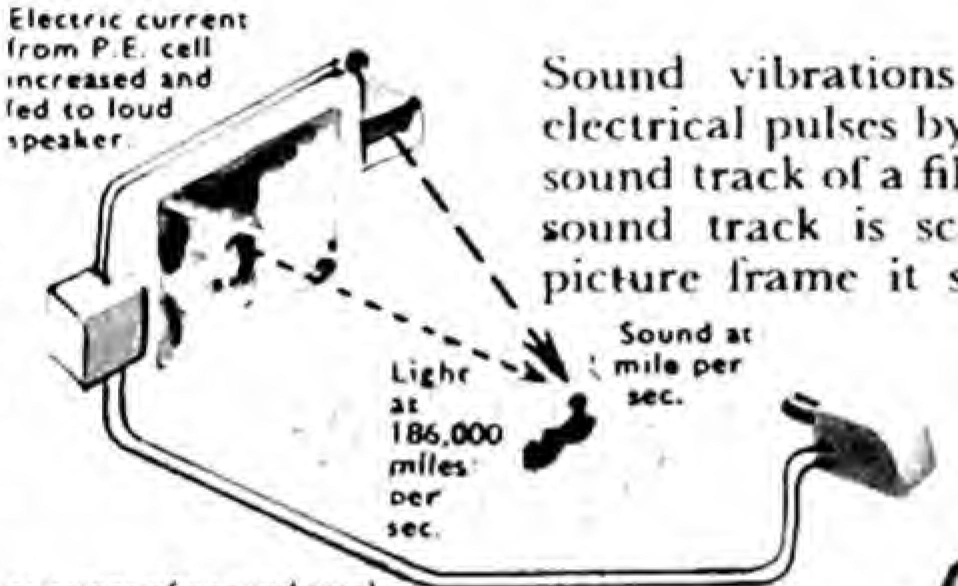


The loudspeaker, which can reproduce both a dog's bark and a violin note, shows that two so different sounds are produced and transmitted in a similar way.

Sound waves are a succession of push-and-pull impulses carried by the air. The air in contact with the source of the vibration is alternately compressed and expanded. This makes the air beyond vibrate at the same rate, and this air, the air beyond still. Thus the pressure waves travel outward. Noise is the effect the vibrations have upon the ear nerves and brain. Pitch of any sound is decided by how *fast* the air is shaken. Loudness by how *hard*. One thing that will stop sound is a vacuum, for in it there is no air to vibrate. Sound waves travel through different materials at different speeds but through all of them at speeds much slower than light. If you watch a race starting in the distance you see the start quite a long moment before you hear the starter's pistol. *See also* SOUND.

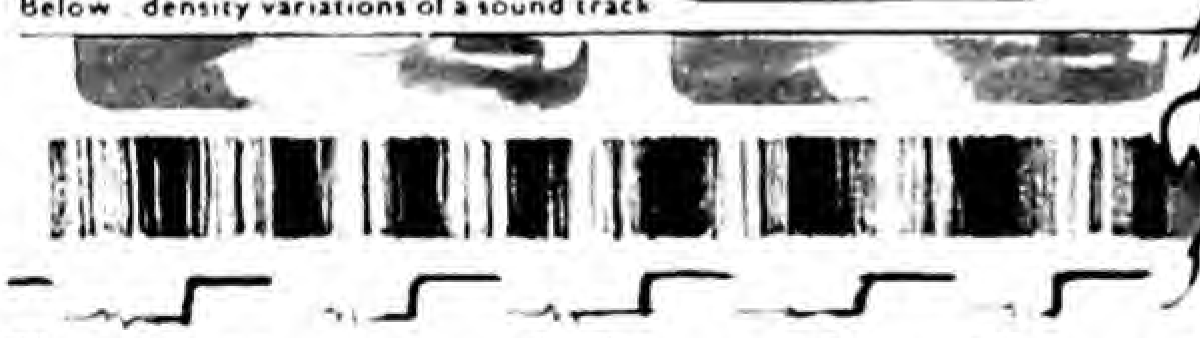


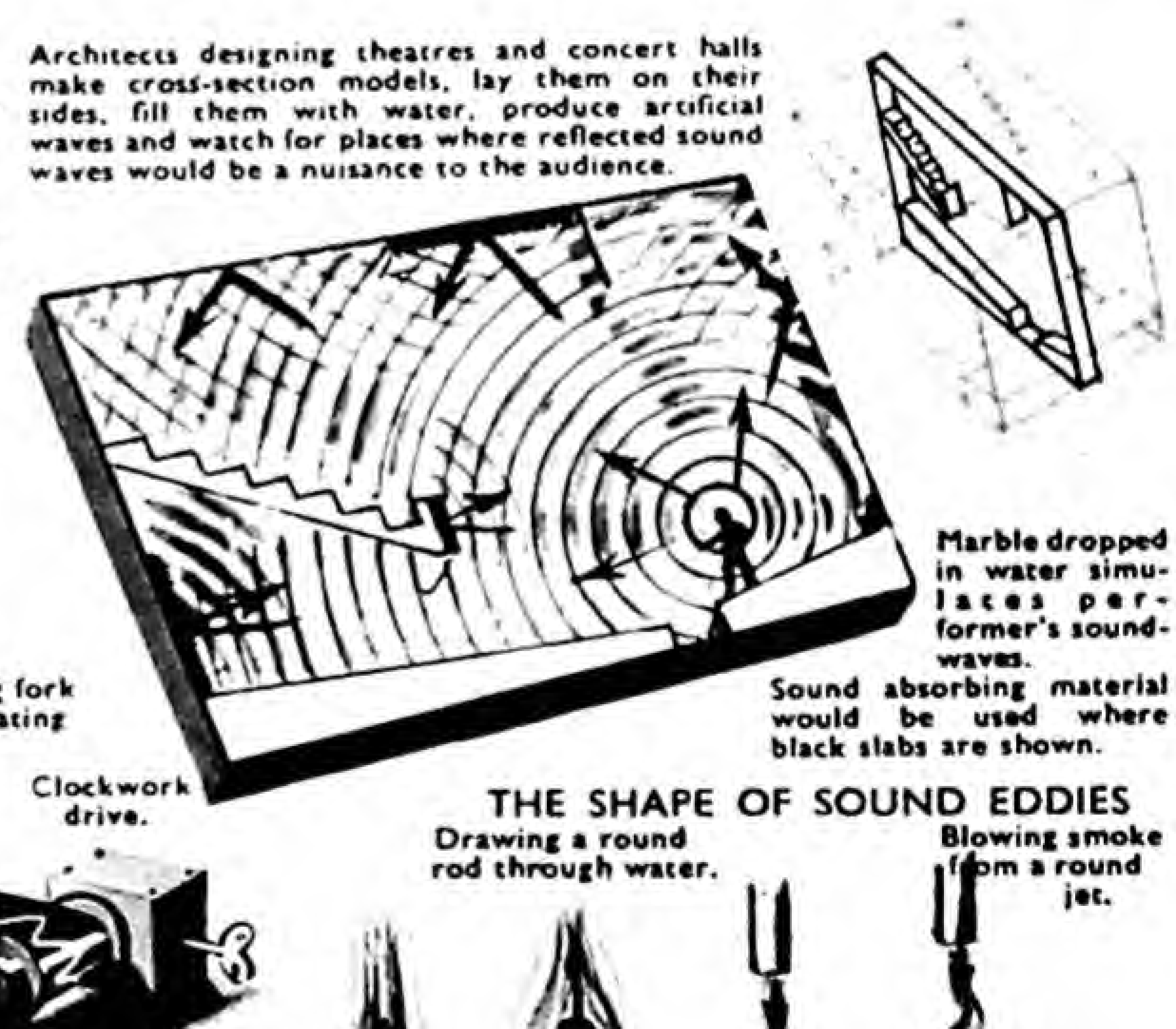
The sound must start from the loudspeaker earlier than the light from the screen if they are to reach the audience at the same time.



Sound vibrations can be changed into electrical pulses by microphones, or, for the sound track of a film, into light waves. The sound track is scanned and converted back to sound earlier than the picture frame it synchronises with.

Below: density variations of a sound track

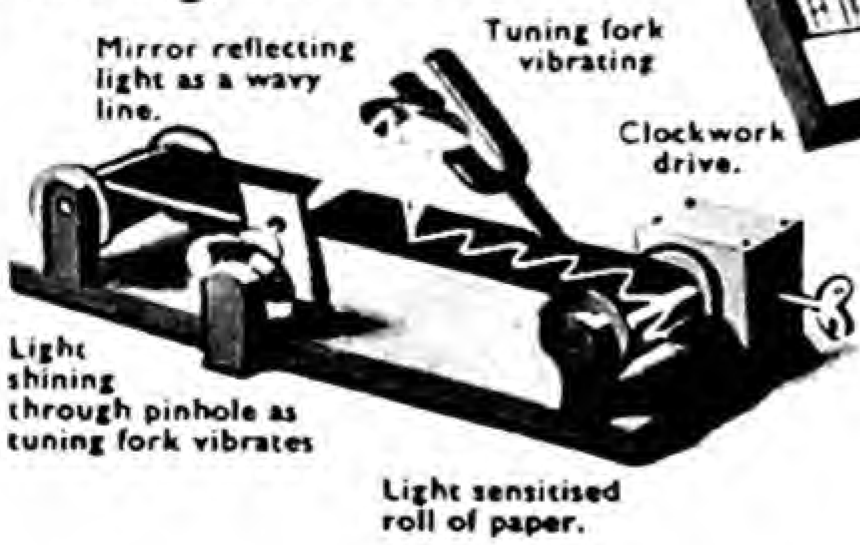




The Patterns of Spreading Sound

Pattern of interfering waves

from two sources. Mercury surface remains stationary where an up wave from one source cancels out a down wave from the other source. This opposition between meeting waves is called "being out of phase". Where two up or down waves meet "in phase" an extra large wave forms.



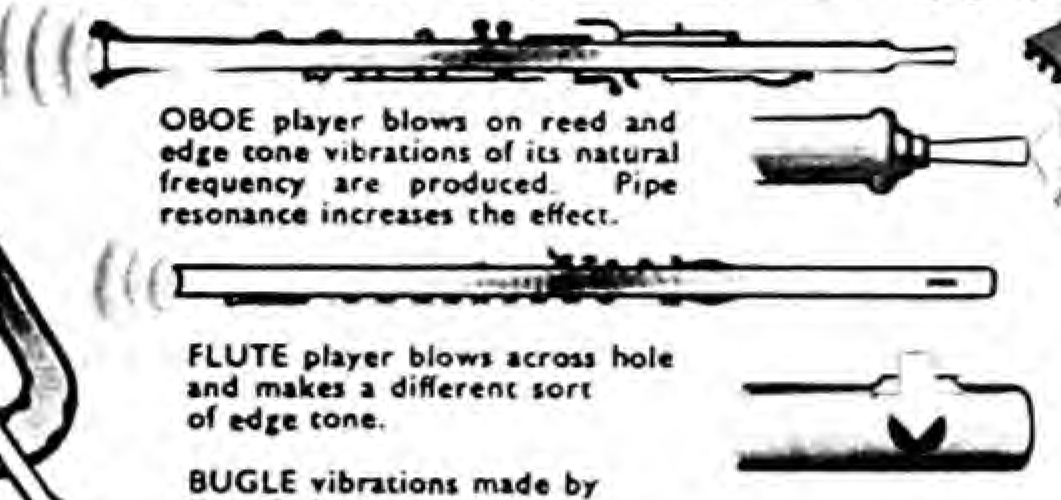
The pattern traced on moving film by light reflected from a mirror fixed to the vibrating tuning fork is a wavy line showing that sound is the result of vibration by the fork. Each complete "push and pull" is a cycle. (∼)

THE SHAPE OF SOUND EDDIES

WE HEAR AS SOUND

HANDBELL producing a spherical wave.

Shape of bugle allows vibrations to "bell" out and shake a great deal of the surrounding air.

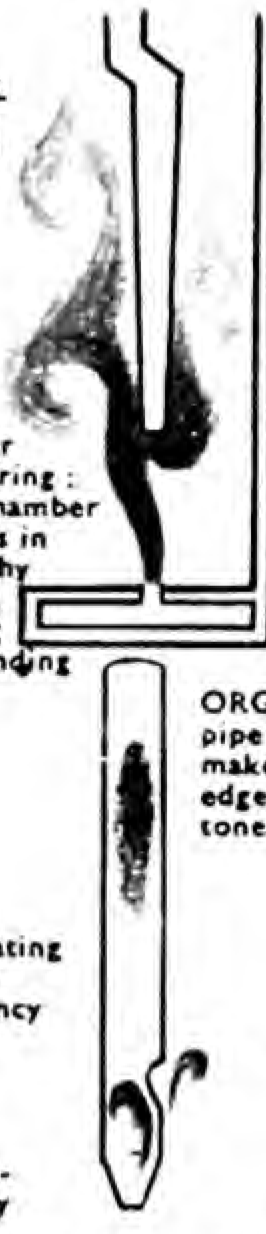


OBOE player blows on reed and edge tone vibrations of its natural frequency are produced. Pipe resonance increases the effect.

FLUTE player blows across hole and makes a different sort of edge tone.

BUGLE vibrations made by lips of player.

GUITAR player vibrates string: sound chamber vibrates in sympathy with it, shaking surrounding air.



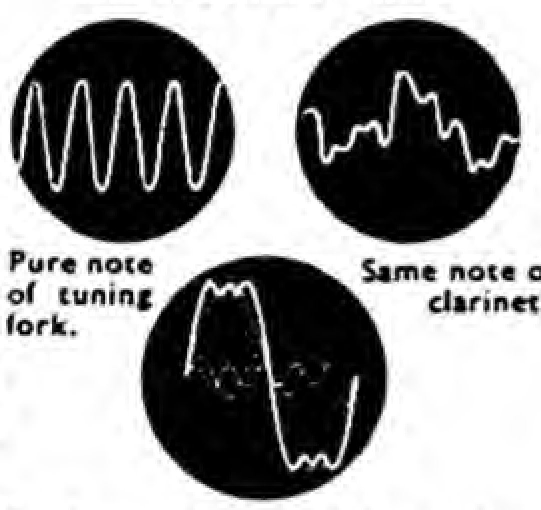
ORGAN pipe makes edge tones

PIANO strings are struck with hammers tripped by lever action of keys

DRUM is a vibrating diaphragm with a natural frequency decided by its tension.

Making Musical Sounds

OSCILLOSCOPE TRACES



Pure note of tuning fork.

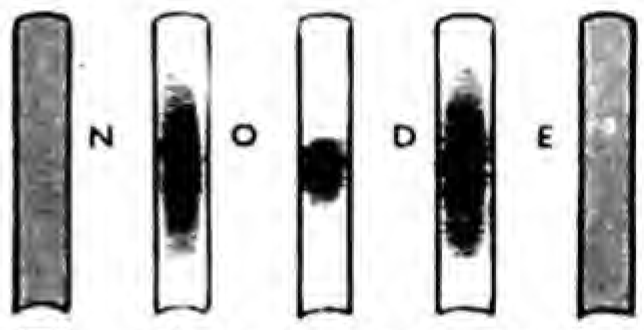
Same note on clarinet.

Fundamental 3rd & 5th harmonics added.

Every stretched string, every pipe or diaphragm, or reed has its own natural vibration frequency. When set in motion each will send out vibrations of its own frequency into the surrounding air. Many wind instruments have bell mouths to help dispatch their sound waves. The point of greatest movement of anything vibrating is called the Anti-Node and the point of no movement is the Node.

The sound waves in the acoustic gramophone are started by the vibrations of a diaphragm which itself moves because the needle follows wavy lines in the record grooves.

Diaphragm

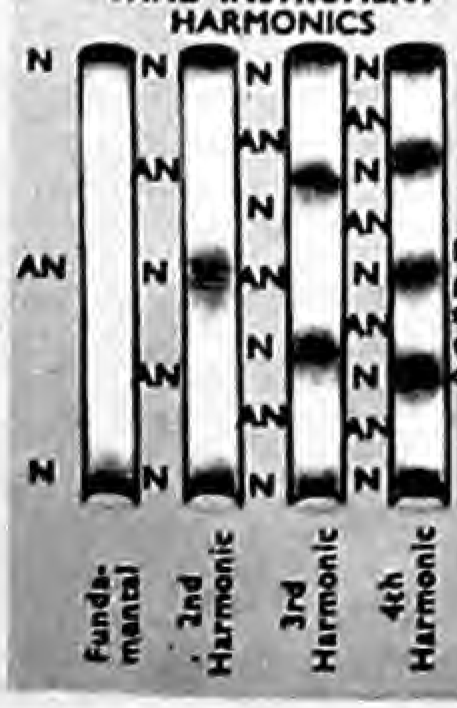


The alternate concentration and dispersal of air particles in a resonant pipe. Vibration is a continuous process made of repeated cycles of movement.

Harmonics

Touch a vibrating string lightly exactly at its halfway point, and instead of the original high point and low point (anti-node) at its centre—it will develop two such points, and the centre will stay still (become a node). The string is then vibrating at its second harmonic. Most musical instruments play many harmonics together with their fundamental (1st harmonic). Each instrument has a different selection of harmonics which gives it a distinctive quality.

WIND INSTRUMENT HARMONICS



Miniature plans of the same drum tuned to different notes.

Plan of cross section

Drum harmonics vary in shape.

Changing The Note

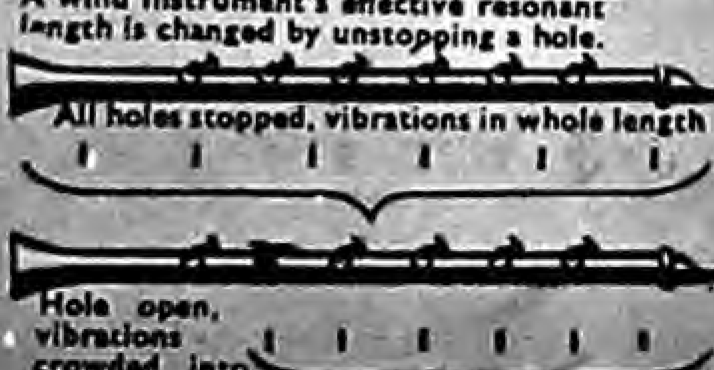
The natural (or resonant) frequency of a pipe or string, can be altered if the length of the *vibrating* part of the pipe or string is changed. A trombone's slide makes it a longer pipe with a lower frequency. String vibrations are affected as well by tension. Instead of shortening the length of a string, to raise its pitch, its tension can be increased (tuning a piano)

The laboratory apparatus for studying harmonics.

The vibrating length of the string is fixed by the two bridges, tension by the weight.

A stringed instrument's note is changed by stopping off, so only part vibrates. Half the length means double the frequency.

A wind instrument's effective resonant length is changed by unstopping a hole.



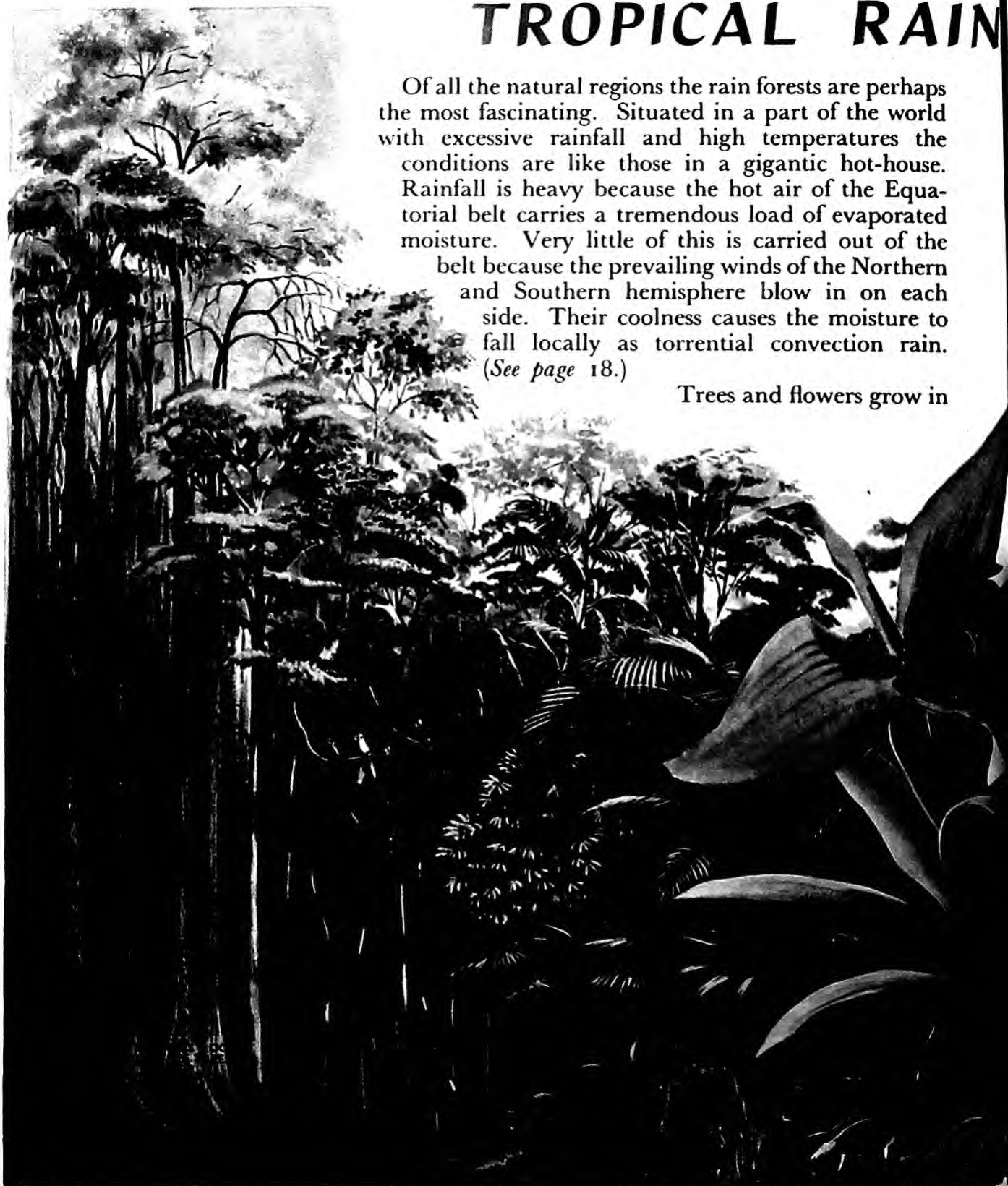
All holes stopped, vibrations in whole length

Hole open, vibrations crowded into shorter pipe so increasing frequency.

TROPICAL RAIN

Of all the natural regions the rain forests are perhaps the most fascinating. Situated in a part of the world with excessive rainfall and high temperatures the conditions are like those in a gigantic hot-house. Rainfall is heavy because the hot air of the Equatorial belt carries a tremendous load of evaporated moisture. Very little of this is carried out of the belt because the prevailing winds of the Northern and Southern hemisphere blow in on each side. Their coolness causes the moisture to fall locally as torrential convection rain. (*See page* 18.)

Trees and flowers grow in



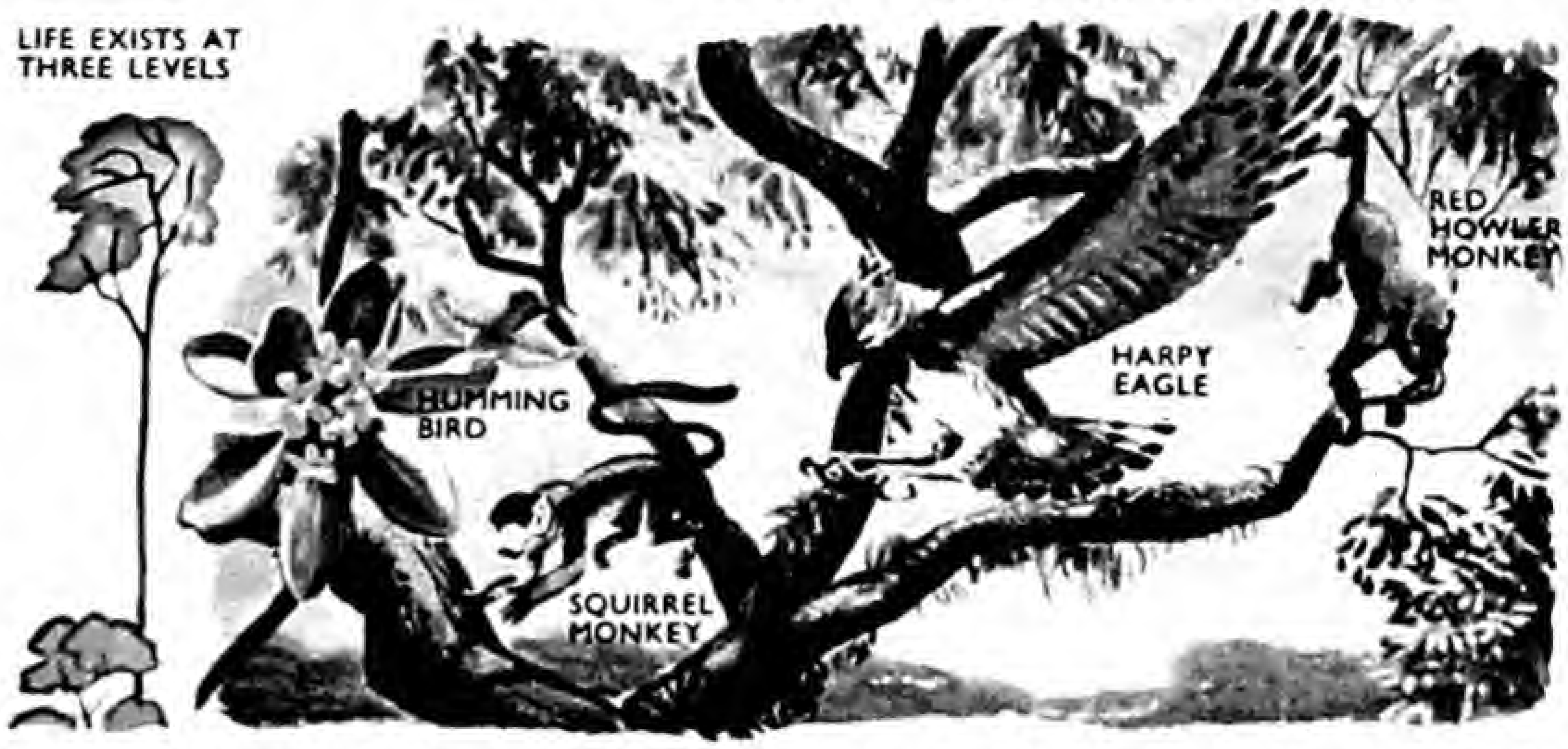
FORESTS

such profusion that the lower part of the forest is always dark, completely closed in by the dense many storied tree canopy. Only the tallest trees break through to the sunlight.

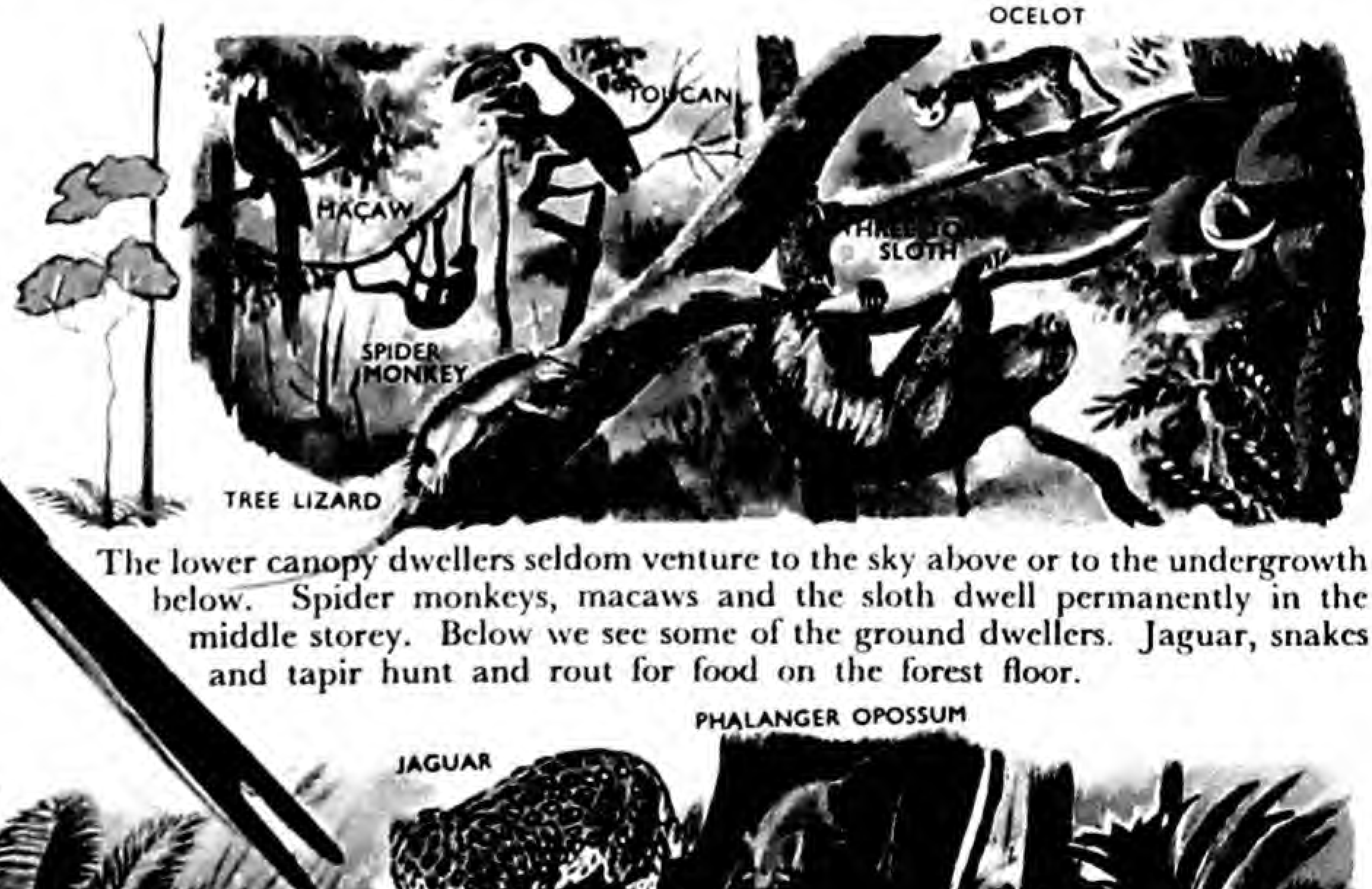
There is no strong seasonal rhythm hence trees may be seen in flower, leaf and bare all within a short space of each other.

Pygmies of the Congo and the Indians of the Amazon live here.

The Rain Forest areas of the world.



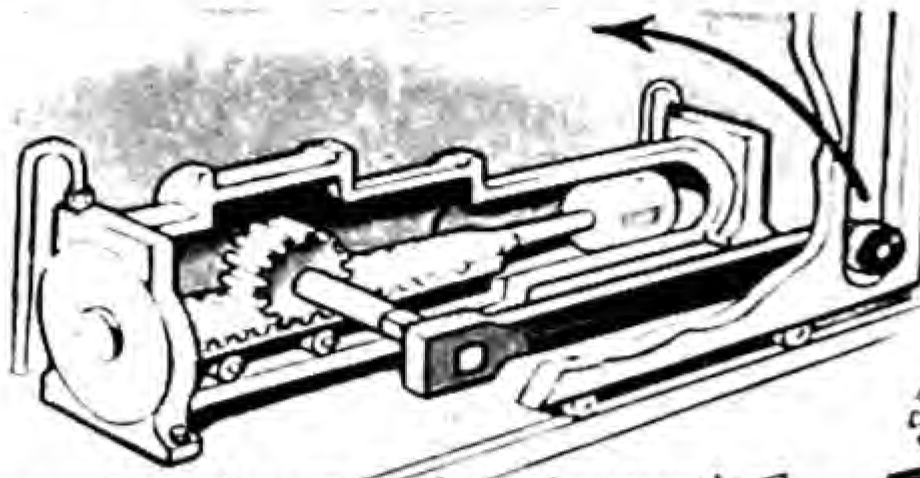
The creatures in the topmost branches of the South American jungle include monkeys and the birds of prey. By day the monkeys usually retire to the safety of the lower canopy but at night they venture aloft to gather fruits and nuts.



The lower canopy dwellers seldom venture to the sky above or to the undergrowth below. Spider monkeys, macaws and the sloth dwell permanently in the middle storey. Below we see some of the ground dwellers. Jaguar, snakes and tapir hunt and rout for food on the forest floor.

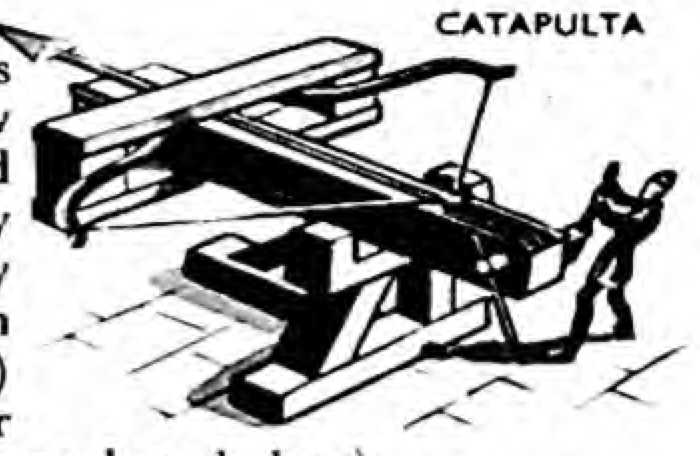
A Humming-bird hovers around an exotic orchid extracting nectar with its long beak.

GEARS, MACHINES AND TOOLS

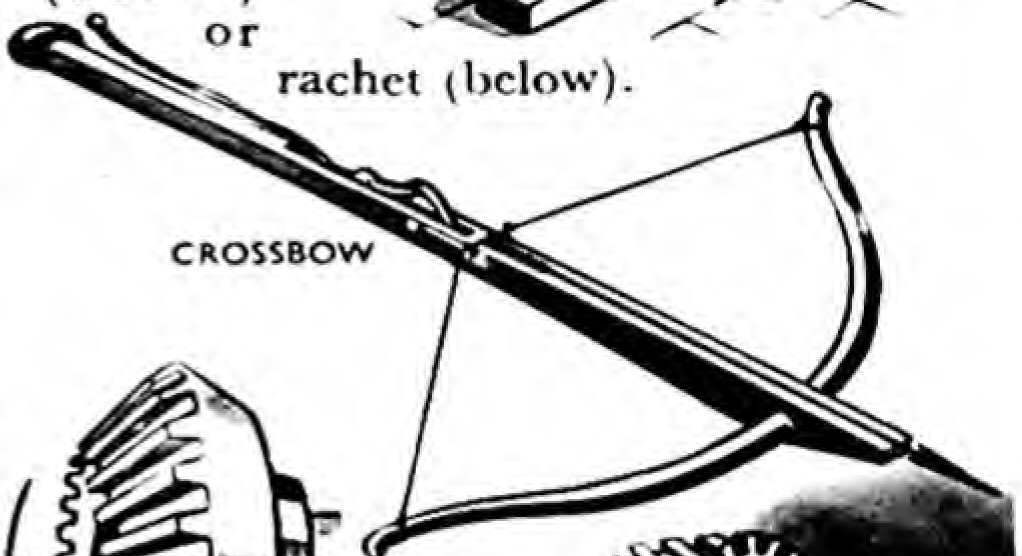


Door of underground train worked by rack and pinion gear. The rack, the flat toothed bar, drives the round pinion.

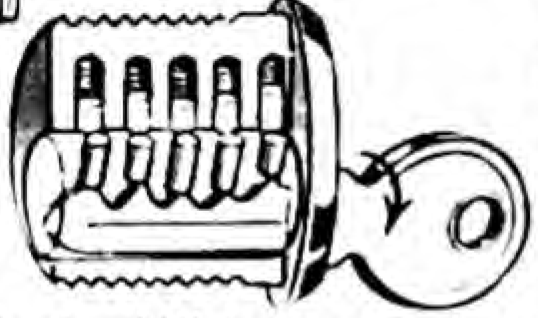
Windmill. Pressure of wind moves sails which turn pinion wheel.



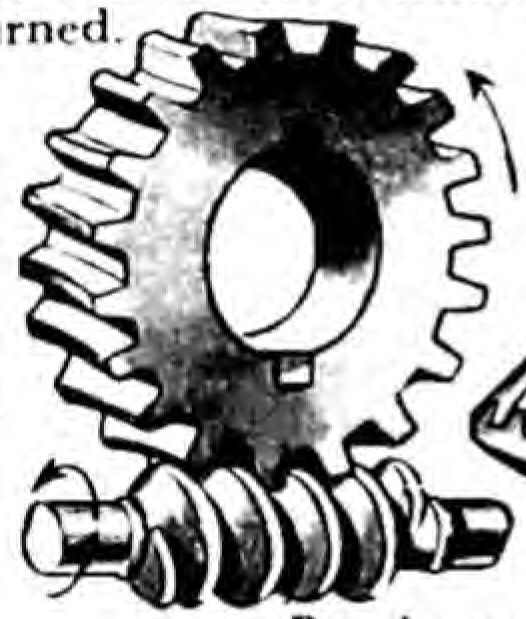
Thongs of bow wound back by pulley winch (above) or rachet (below).



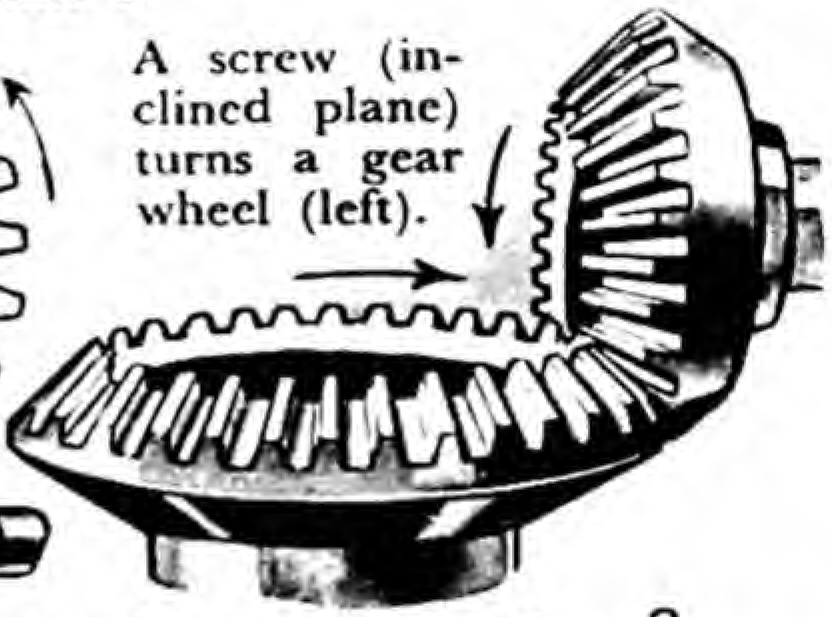
Lever and cam action draws back latch when handle is turned.



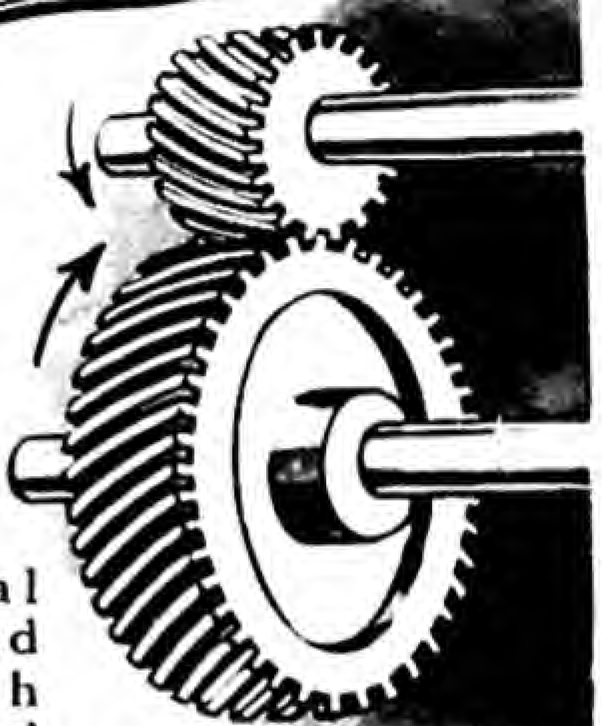
Yale lock. With correct key pins are lifted to equal height in holes and lock turns.



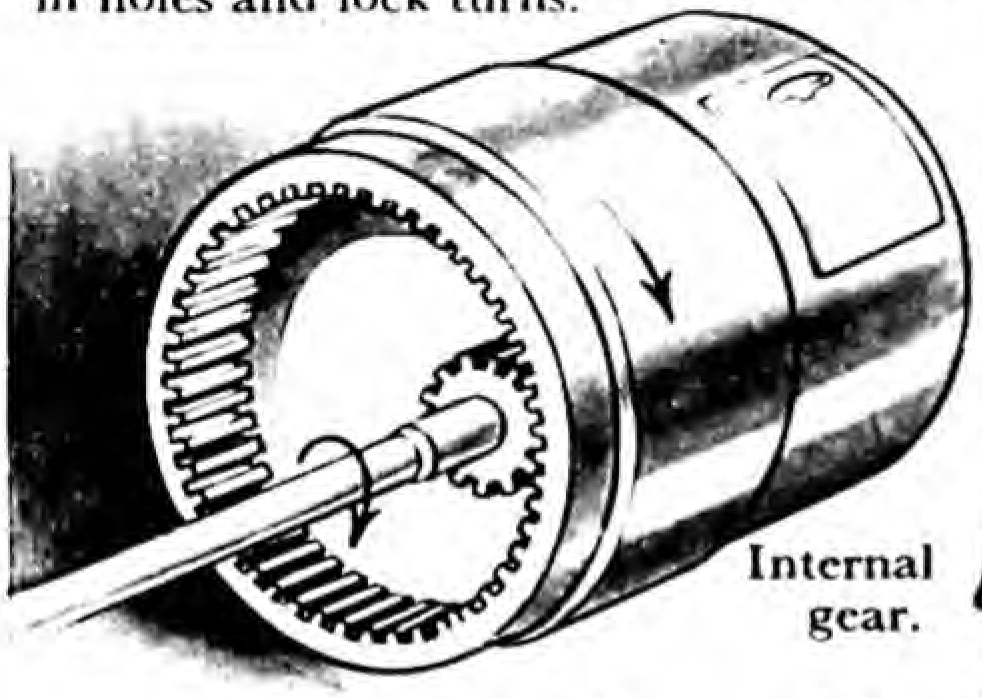
A screw (inclined plane) turns a gear wheel (left).



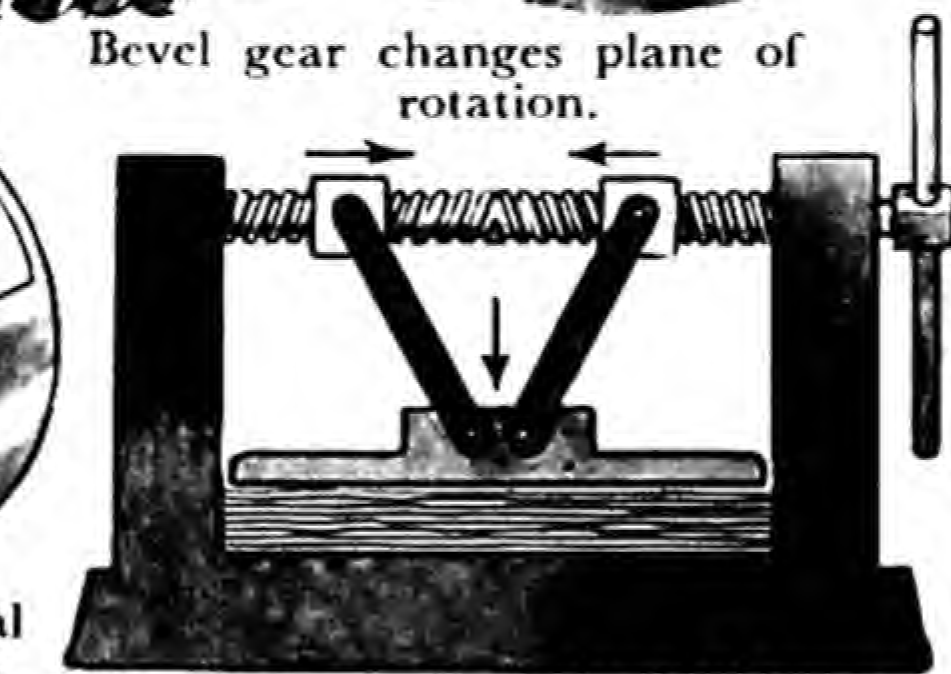
Bevel gear changes plane of rotation.



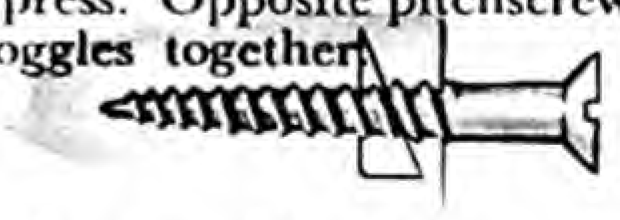
Helical (angled tooth gear) used where thrust on teeth is great.



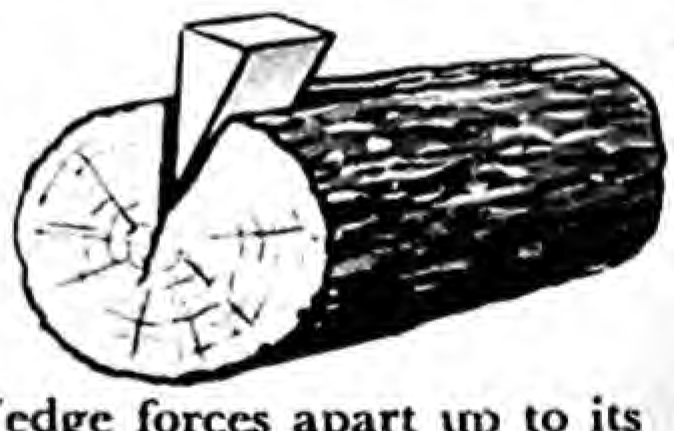
Internal gear.



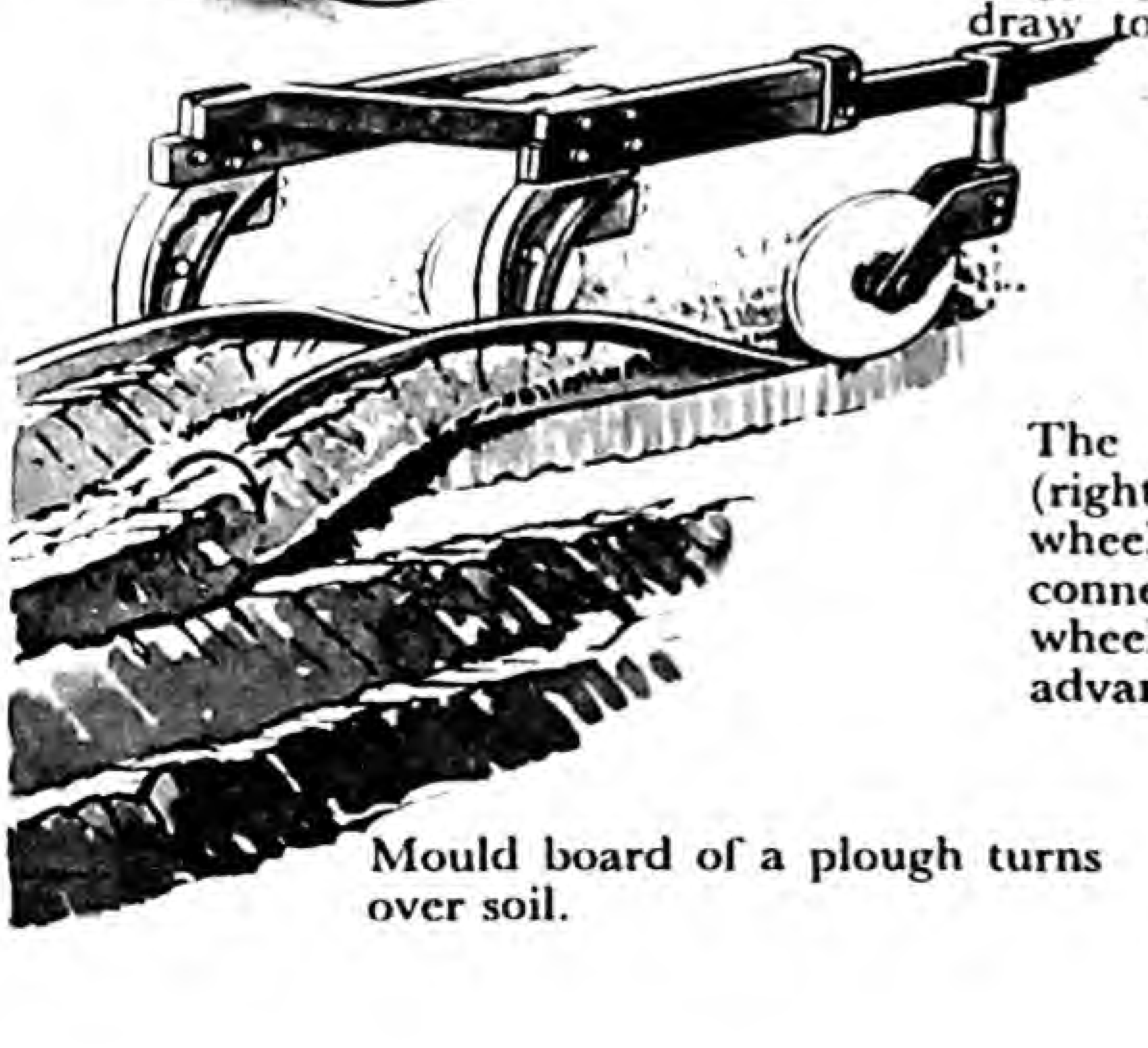
Toggle press. Opposite pitchscrews draw toggles together.



Screw. (Spiral inclined plane).

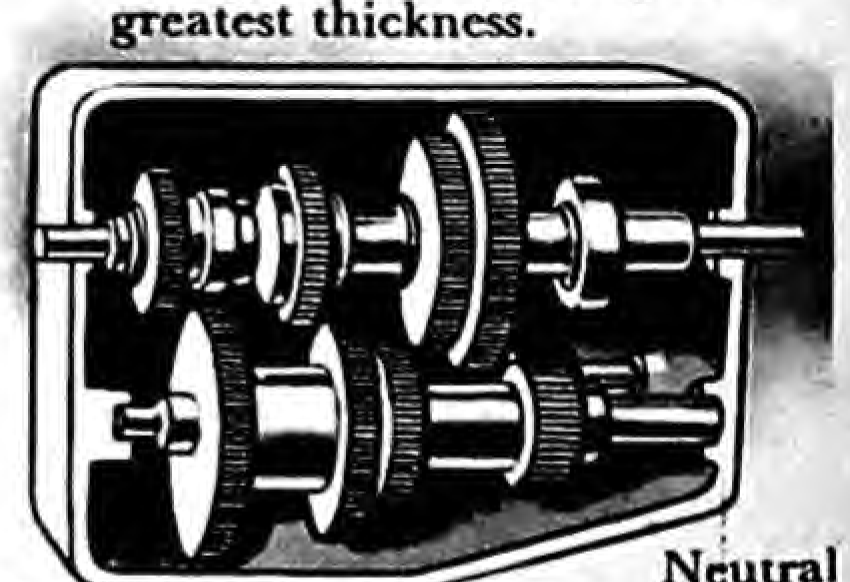


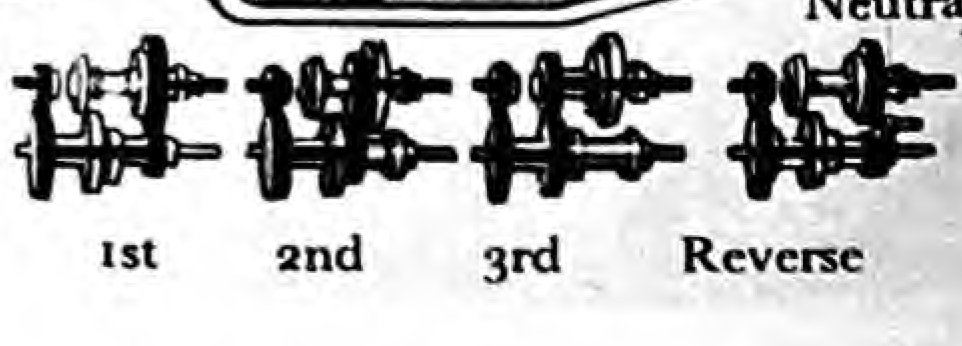
Wedge forces apart up to its greatest thickness.

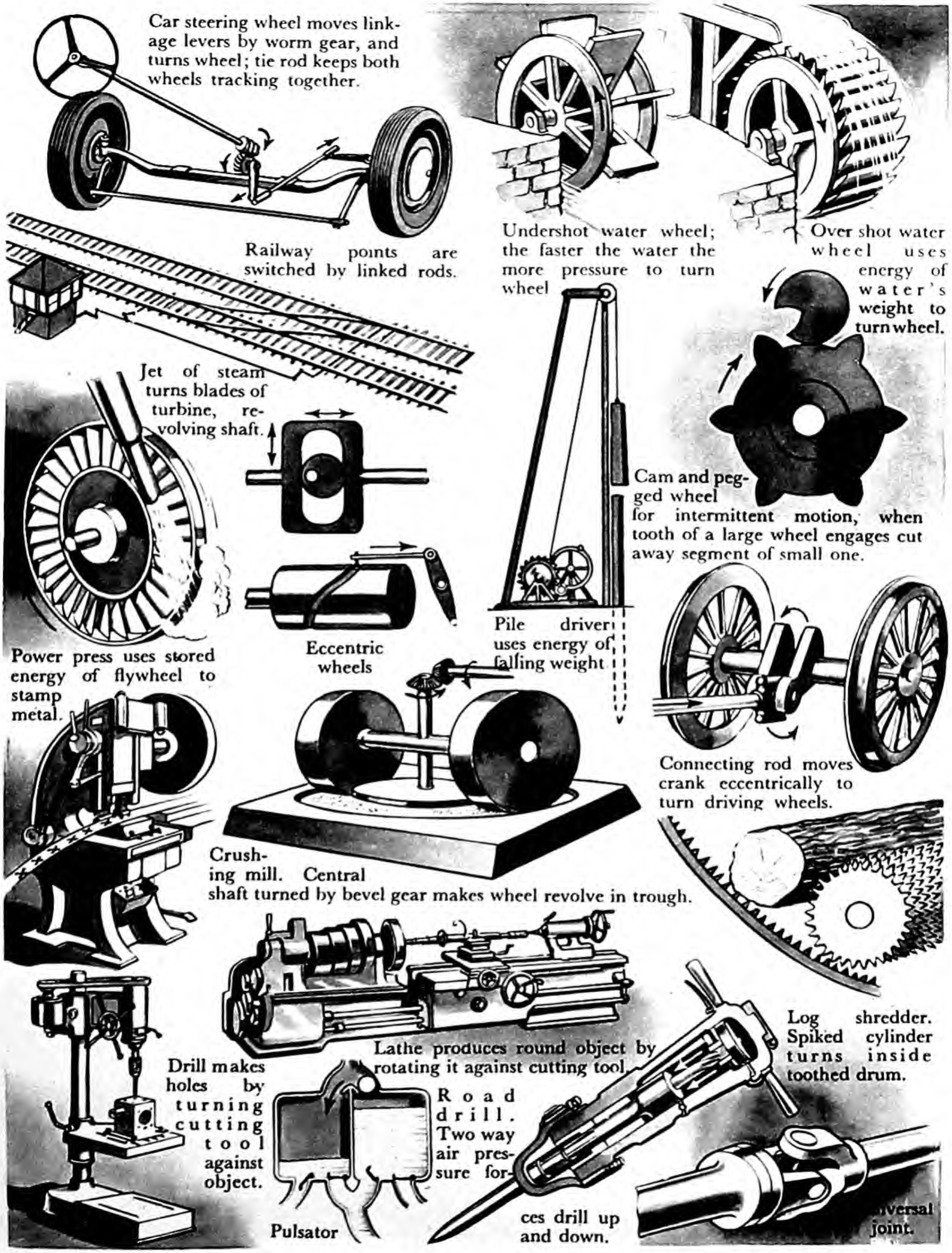


Mould board of a plough turns over soil.

The motor car gear box (right) combines different gear wheels of various ratios to connect a steady speed to the wheels to obtain mechanical advantages.







Car steering wheel moves linkage levers by worm gear, and turns wheel; tie rod keeps both wheels tracking together.

Undershot water wheel; the faster the water the more pressure to turn wheel

Over shot water wheel uses energy of water's weight to turn wheel.

Railway points are switched by linked rods.

Jet of steam turns blades of turbine, revolving shaft.

Cam and pegged wheel for intermittent motion, when tooth of a large wheel engages cut away segment of small one.

Pile driver uses energy of falling weight

Eccentric wheels

Power press uses stored energy of flywheel to stamp metal.

Connecting rod moves crank eccentrically to turn driving wheels.

Crushing mill. Central shaft turned by bevel gear makes wheel revolve in trough.

Log shredder. Spiked cylinder turns inside toothed drum.

Lathe produces round object by rotating it against cutting tool.

Drill makes holes by turning cutting tool against object.

Road drill. Two way air pressure forces drill up and down.

Pulsator

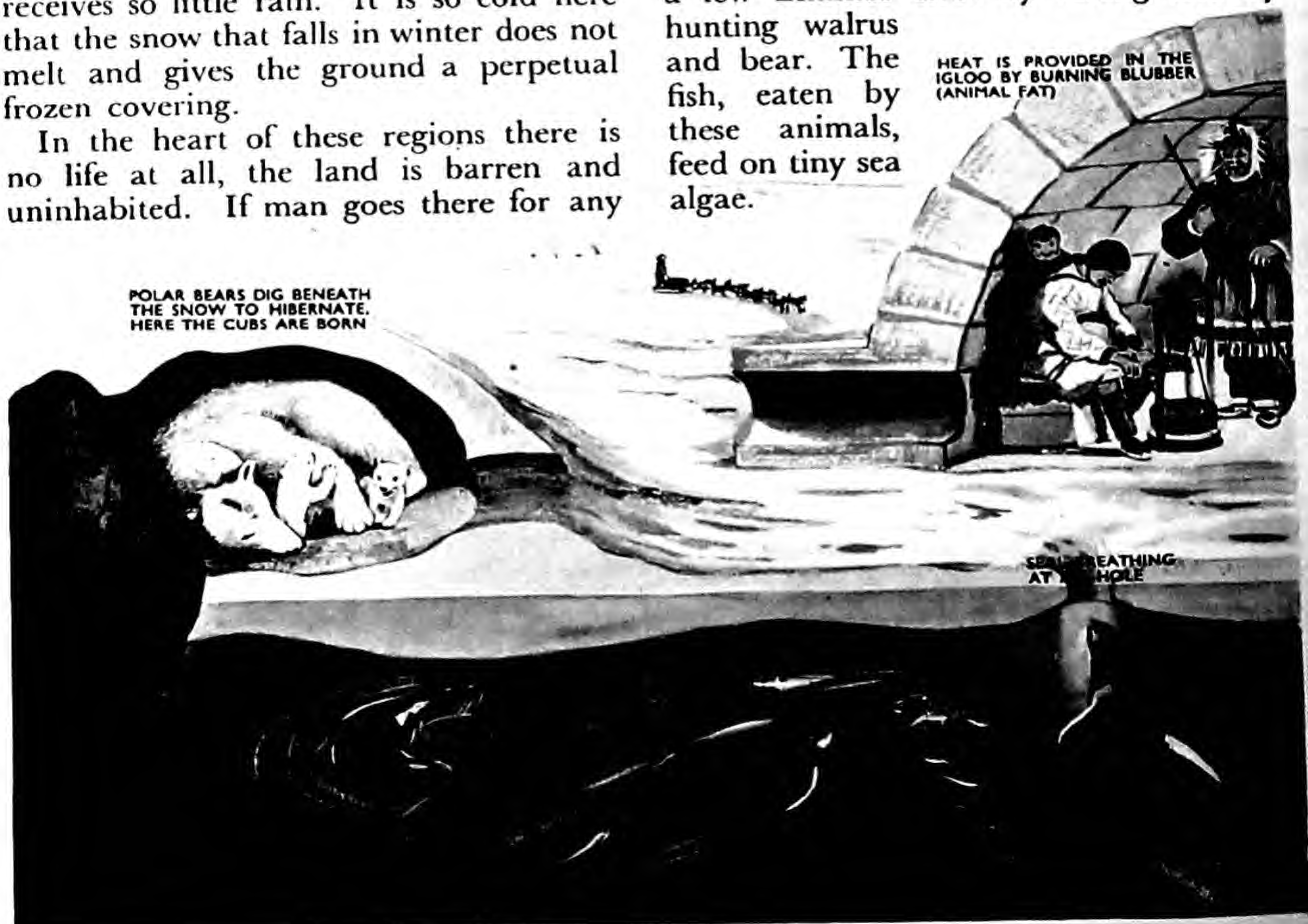
[Un]iversal joint.

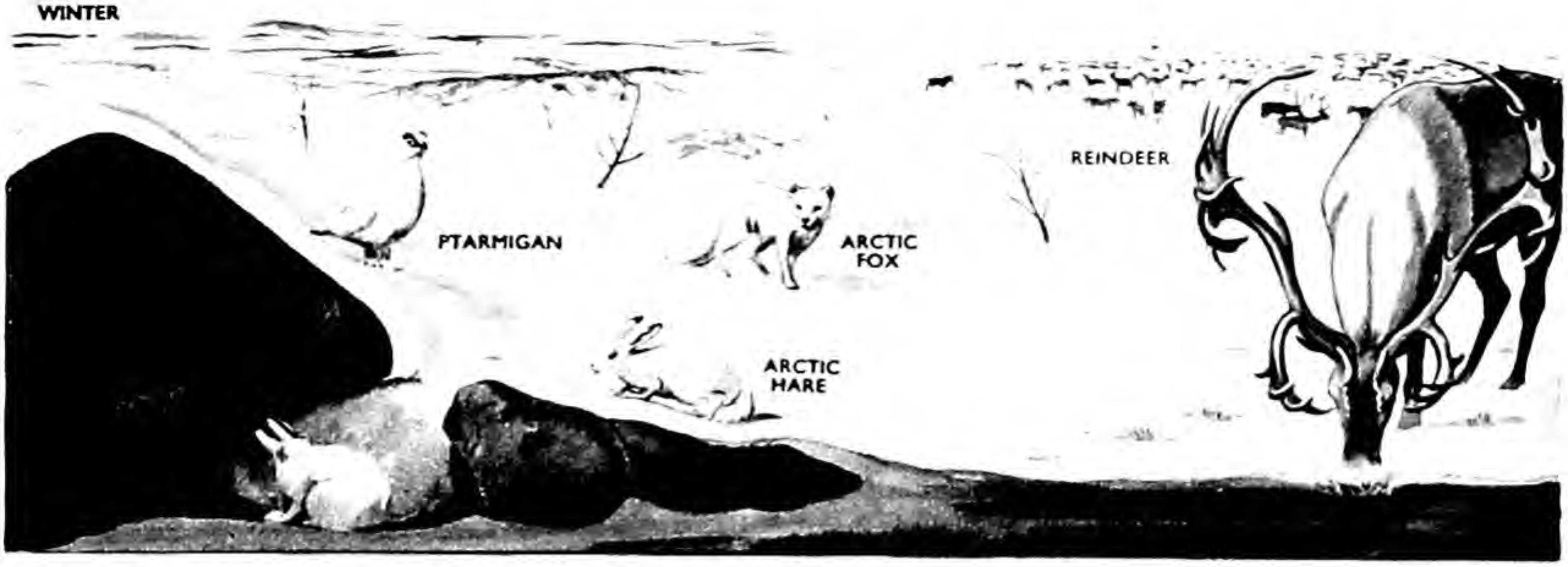
COLD LANDS

DESERTS

These are found in Greenland and the Antarctic. They are areas which receive snow equal to less than ten inches of rain each year and are called ice deserts because it is usual to regard as desert any land which receives so little rain. It is so cold here that the snow that falls in winter does not melt and gives the ground a perpetual frozen covering.

In the heart of these regions there is no life at all, the land is barren and uninhabited. If man goes there for any reason he must take with him all the things he needs in order to live. On the coastal margin of the ice deserts life is possible because the ice thaws in summer. On the south-west coast of Greenland a few Eskimos exist by fishing and by hunting walrus and bear. The fish, eaten by these animals, feed on tiny sea algae.





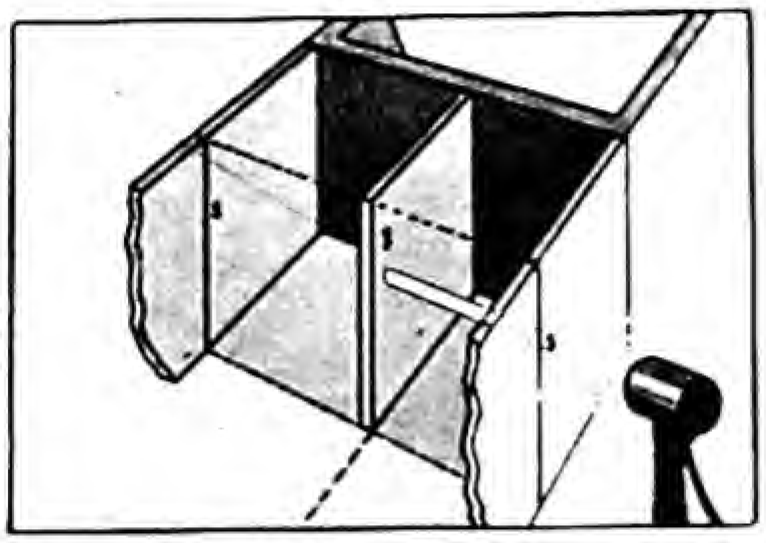
The Tundra changes completely from winter bleakness to summer splendour. During the short summer sunshine mosses and lichens grow. The animals change their coats.

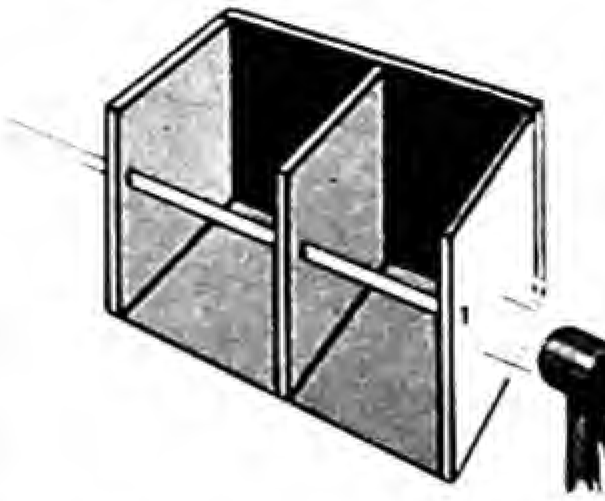
Tundra

The treeless plains found in Siberia and Northern Canada make up the Tundra. Here there are short cold summers and long, very cold winters ; not cold enough to be covered by snow throughout the year, yet not warm enough for trees to occur. Under the snow, mosses and lichen survive. The nomadic Lapps in Siberia have herds of reindeer which must keep moving to find lichen to feed on. The Eskimos of Northern Canada have settled communities because they are hunters.

THE STORY OF LIGHT

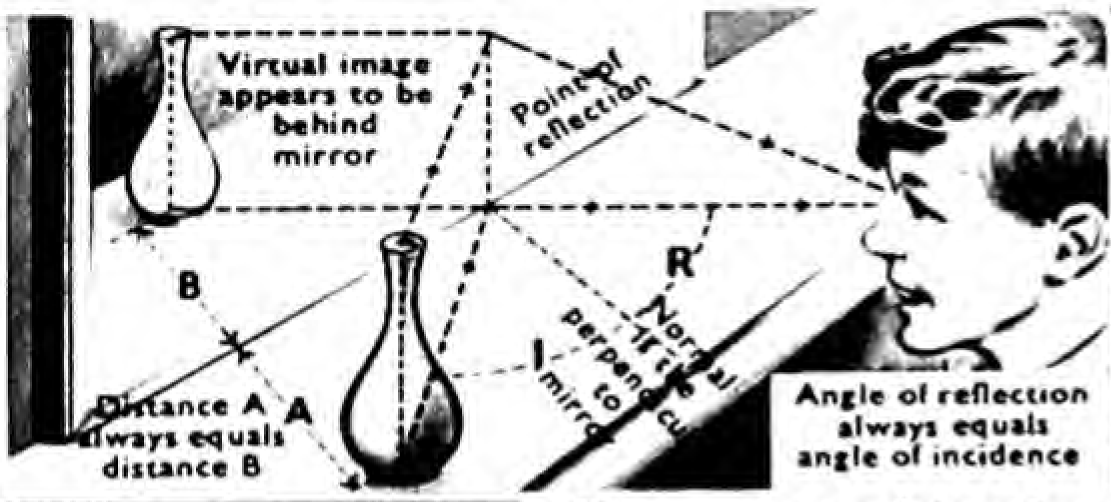
The nature of light is still a mystery, though at least two theories concerning its nature exist. For some purposes it is best to regard light as electro-magnetic vibrations (i.e. akin to radio waves). Unlike sound light does not need a material substance to travel in, since it can travel across a vacuum—it comes to us from the sun across empty space. The speed of light has been measured, and found to be 186,000 miles per second. Optics is the name for the study of the behaviour of light, the way it travels, its passage through different substances, and its relation to what we call colour. *See also* SHADOWS, MIRRORS AND LENSES.

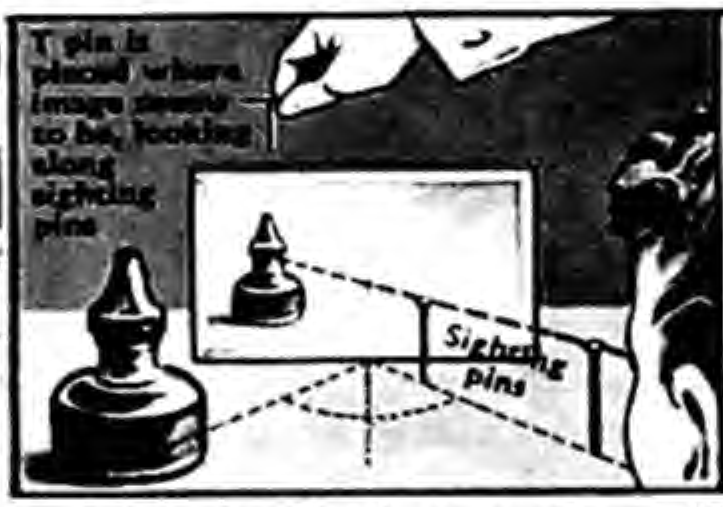


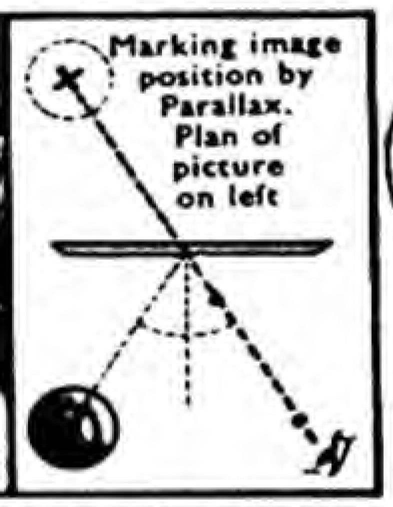


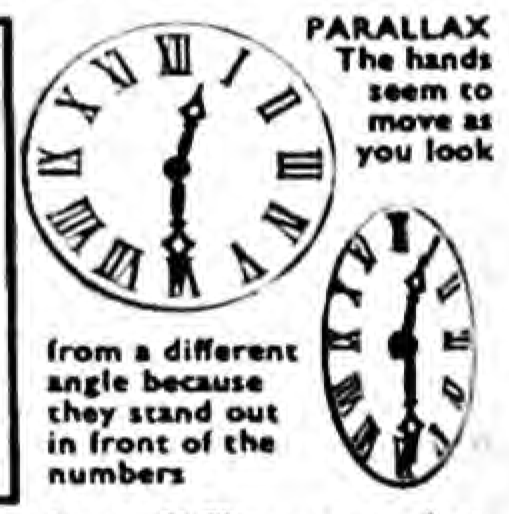
Light travels in straight lines. The beam of light shining through the keyhole of the inner door is stopped by the middle door. But if the keyhole of the middle door was in line with the other two, the beam could shine through all three.

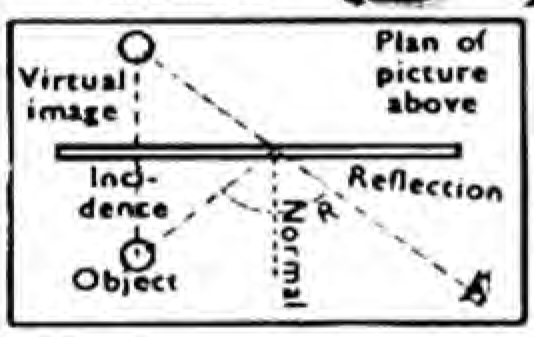
A shadow is all the dark space on the far side of a lighted object. Straight lines drawn from the edge of the profile the shadow forms, touching the edge of the shadowed object, point to the source of light. The shape and size of the profile depend on the position of the object between the light and the reflecting surface. (*See page* 159.)



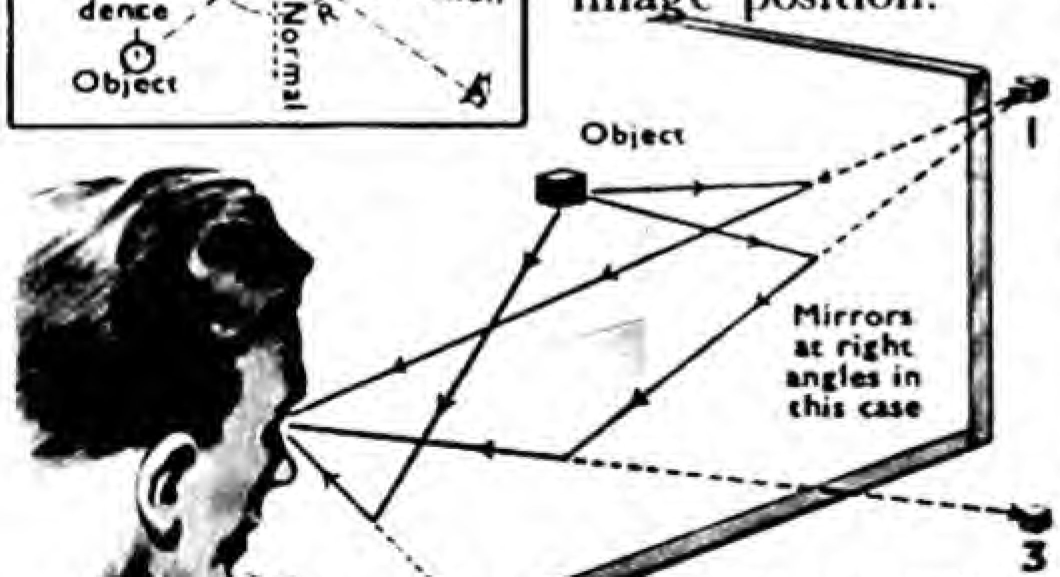






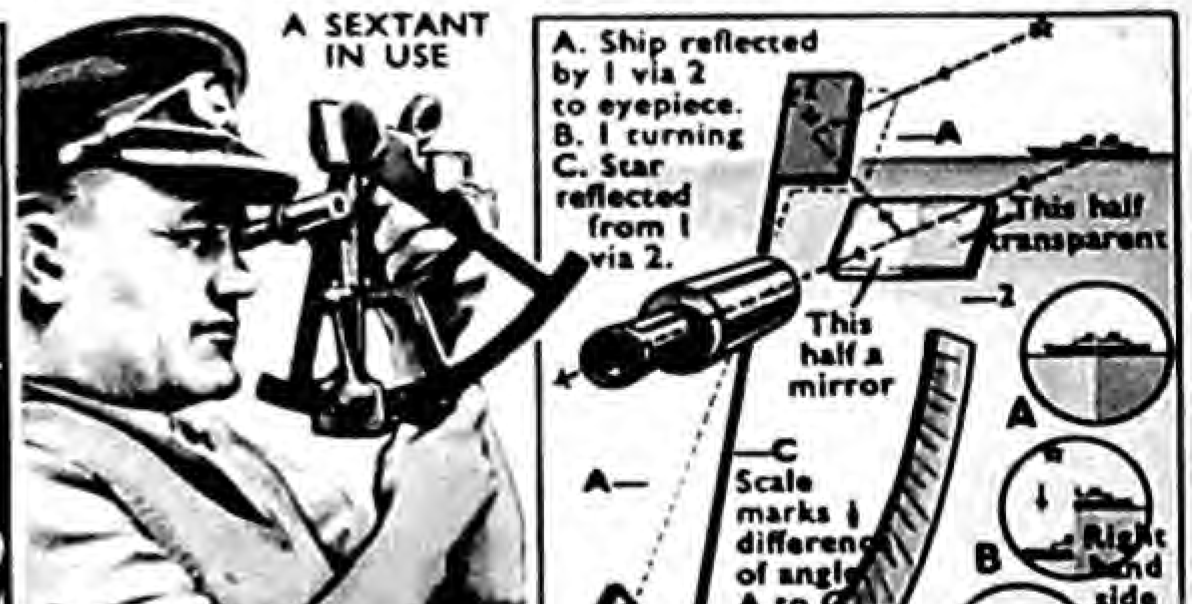


For every position from which you look at a plane (flat) mirror there is a different point of reflection. In second picture if eye is moved to left and T pin seems to move left too (parallax) it is too far out. When from every view point there is no parallax T pin is in image position.

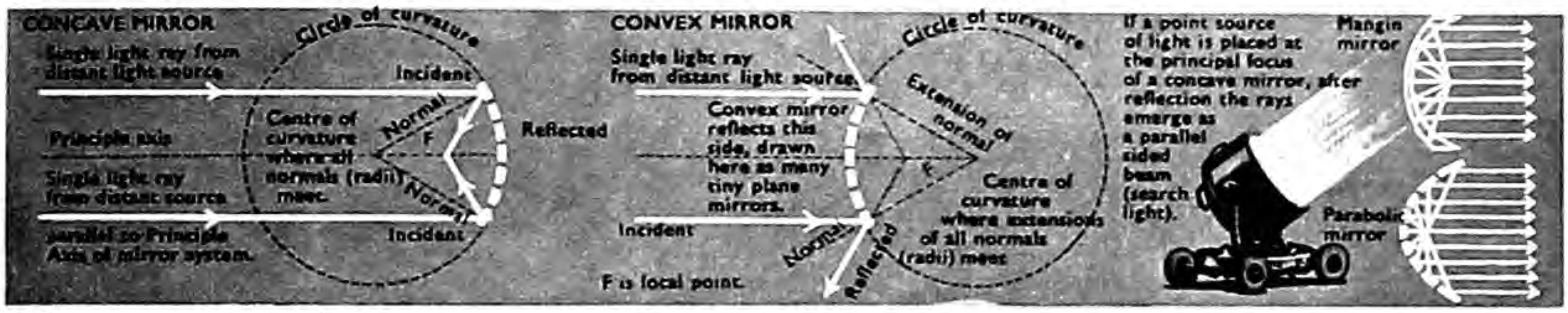


Two mirrors in different planes, each form a direct image (1 and 2). As the angle between the two mirrors is made smaller the possibility of seeing extra images increases.

You can see round a corner although light always travels in straight lines.



Mirror 1 has to be turned until the reflection of the star via mirror 2 is seen alongside the horizon (ship) directly seen. Unless the angle between the normal of 1 and a point on 2 is equal to the angle of incidence to 1 of the star's light, the reflected light ray will not strike 2. To make it do so 1 is turned through half the angle of difference—ship to star. (*See page* 117.)



Curved Mirrors

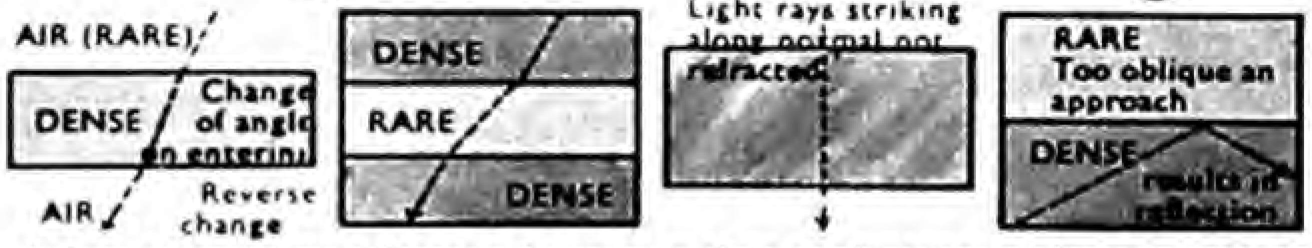
Any minute part of a curved mirror can be thought of as acting like a tiny plane (flat) mirror. The reflecting surface of each tiny mirror is a tangent to the circle of curvature of the whole mirror, and the normal (the line perpendicular to the plane mirror at its centre point) of each will pass through the mirror's centre of curvature (i.e. will be a radius of the curvature of the mirror). A single ray of light travelling from the edge of an object strikes one of the tiny mirrors at the Point of Incidence, making a certain angle with its normal (which is also the Radius of Curvature). The ray is reflected along a line that makes an *equal* angle on the other side of the Radius. This is the same as for reflection in any plane mirror.

But the curious thing is that when the little mirrors are grouped into this CONCAVE pattern, rays of light parallel with the principal axis of the mirror system must, after reflection, no matter at which tiny mirror, all pass through one point known as the focal point. This is on the mirror's principal axis exactly half way between the mirror and its centre of curvature. Thus focal length $f = \frac{1}{2}$ radius.

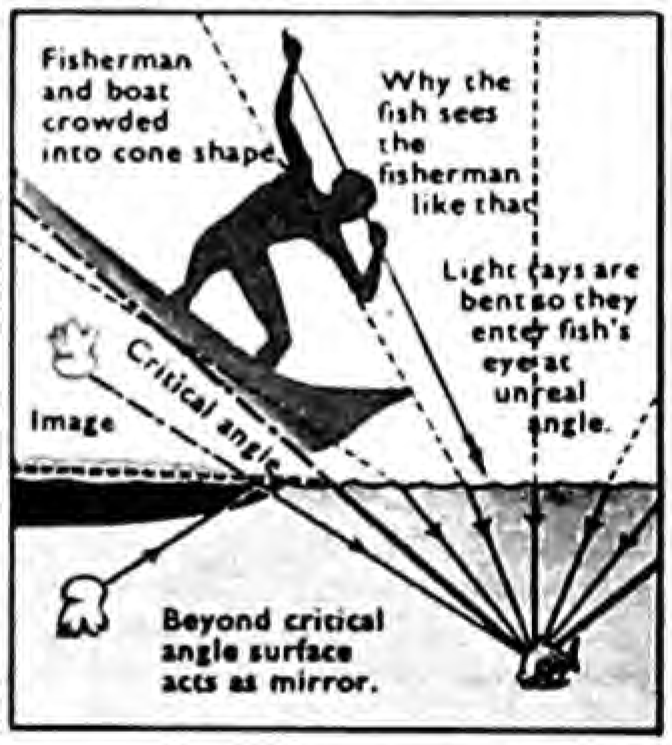
Similarly with a CONVEX mirror, but the reflected rays appear to originate from a point behind the mirror (i.e. the focal point is virtual or imaginary—not real). *See page* 115.

Refraction - The Bending of Light Rays

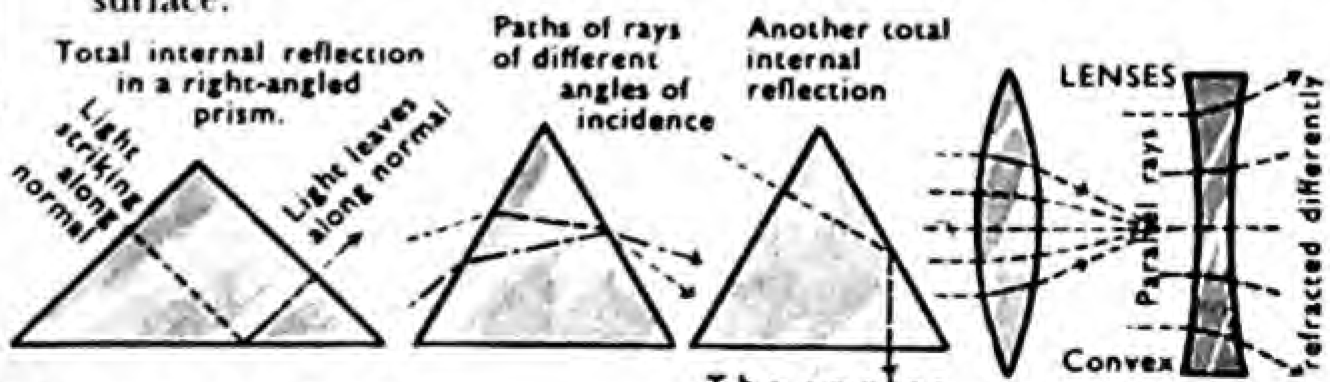
Refraction distorts reality even more for the fish (looking from water into air) than for the fisherman.



Refraction varies for different substances in their combinations of dense to rare, or rare to dense. If a light ray strikes another medium along its normal there is no refraction—if you look straight down into water you see a stone at the bottom in its true direction. The amount of bending at any surface is standard, so a too oblique approach from dense to rare will result in reflection not refraction.



The picture the fish will see is confined to a cone into which the fisherman and his harpoon are unevenly fitted. And the light rays will enter the fish's eye at angles that make the fisherman seem to be hovering over the surface of the water. Beyond this cone the fish can see only reflections of things under the water surface.



The angle at which light strikes the long face is greater than the critical angle of glass. So the prism becomes a highly efficient mirror.

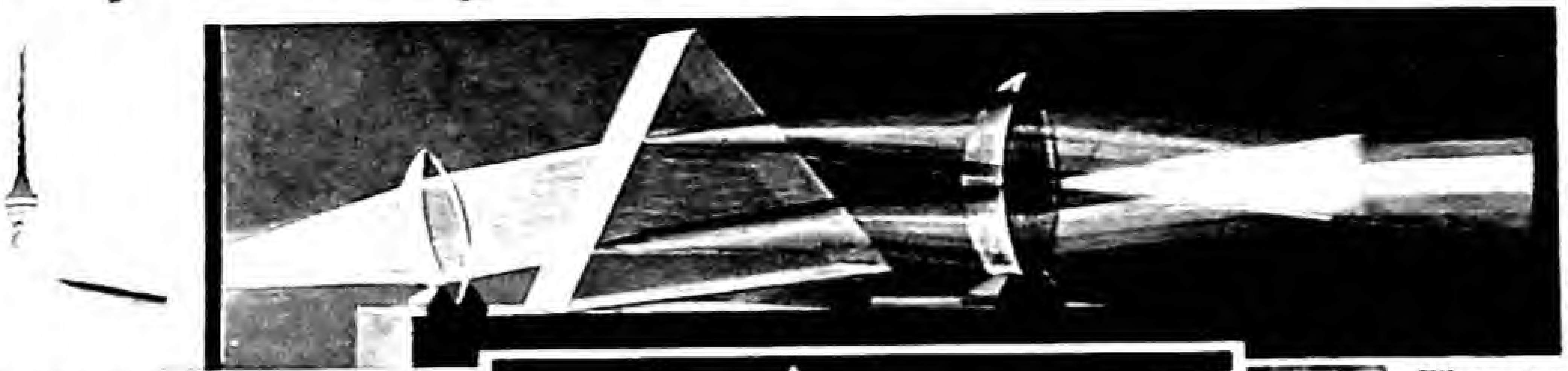
Varying angles of incidence produce varying angles of refraction.

The angles formed by the sides of a prism help to decide if any particular incident ray will be reflected.

A lens acts as if made of parts of many different shaped prisms.

A light ray bent on entering one side of a prism will strike the far side at a quite different angle (depending on the shape of the prism). So, unlike refraction through a parallel sided slab (*top*), the ray takes a quite different direction on emerging. A lens presents as it were the sides of many prisms set at different angles, so refracting parallel rays differently. (*See pages* 10, 11.)

Separating the Colours of Light

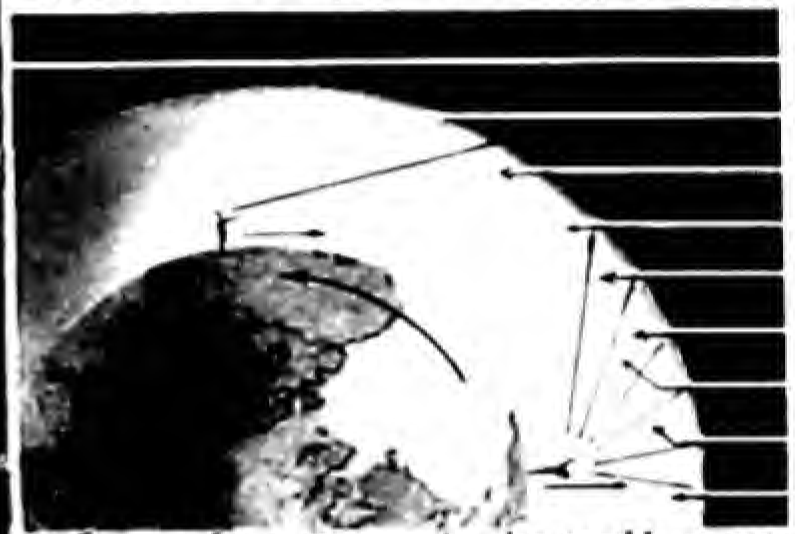


A prism will do more than merely bend light. If a parallel beam is shone into it at the correct angle the prism will refract the different colours, of which the white light is made up, differently, so they emerge at slightly different angles as a spectrum. Red is bent least, violet most. A convergent lens will then focus the beams of coloured light into separate bands.

If one prism will split white light into the spectrum colours another (upside down to reverse the refraction angles) will reform them into white light.

Beams of equal brightness of red, blue and green light combine to make *white*. This is colour addition. Filters (top right) are subtraction.

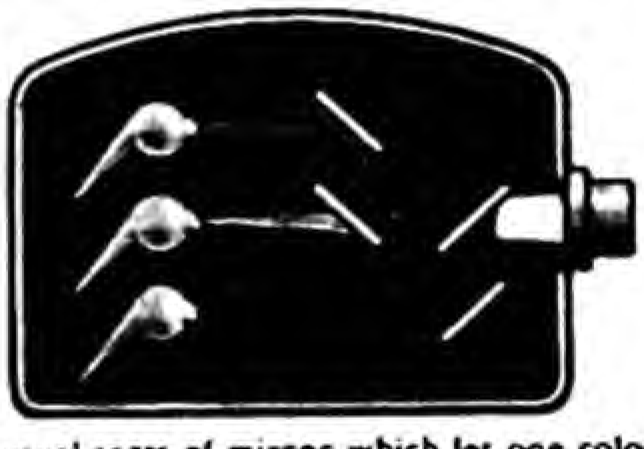
Filters made of glass of the primary colours, red, blue and green, will absorb out of white light all rays not in their own part of the spectrum.

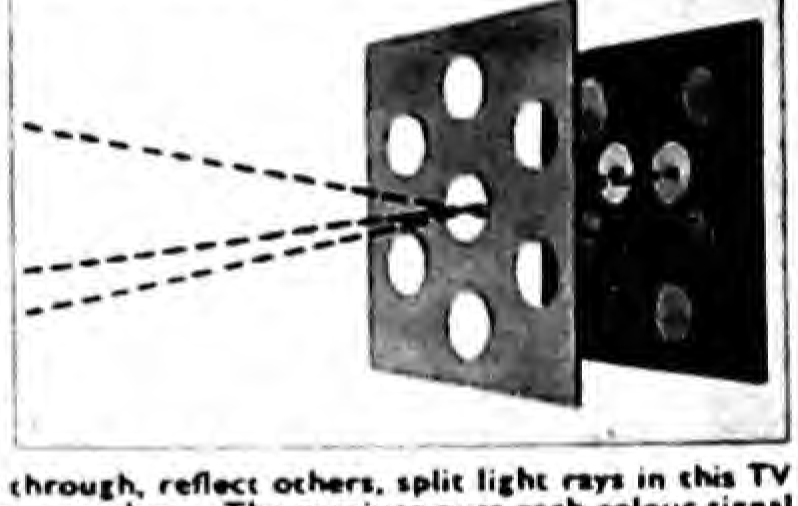


Light rays from the sun in the earth's atmosphere. At midday you are so placed as to receive the blue rays, dispersed through the largest angle. At sunset you are placed so that you only receive the red and yellow rays, dispersed through smaller angles.

Colour Television

The simplest type of colour TV whirls three colour filters past the screen, so fast that the eye retains the effect of all three long enough to mix them. The varying brightness of the ordinary TV screen through each filter in turn gives the effect of many colours (look at the ballet dancers above). Of course the red filter must be in front of the screen at the same moment that at the camera end the equivalent filter is in front of the camera tube; this is done by a synchronising signal, so the right amount of brightness shines through each filter.

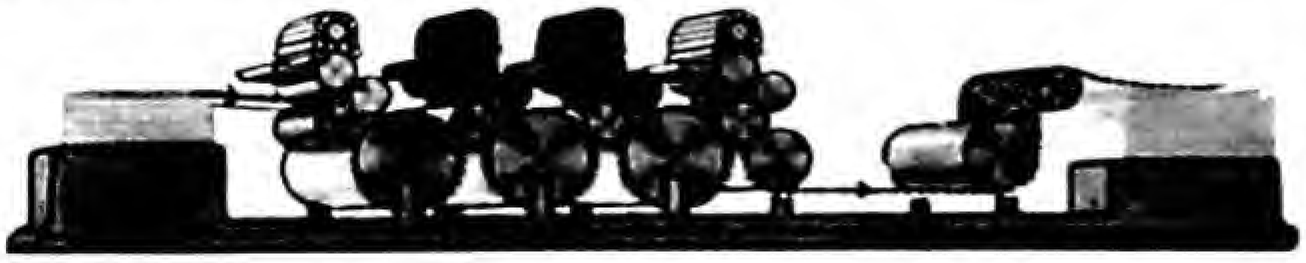




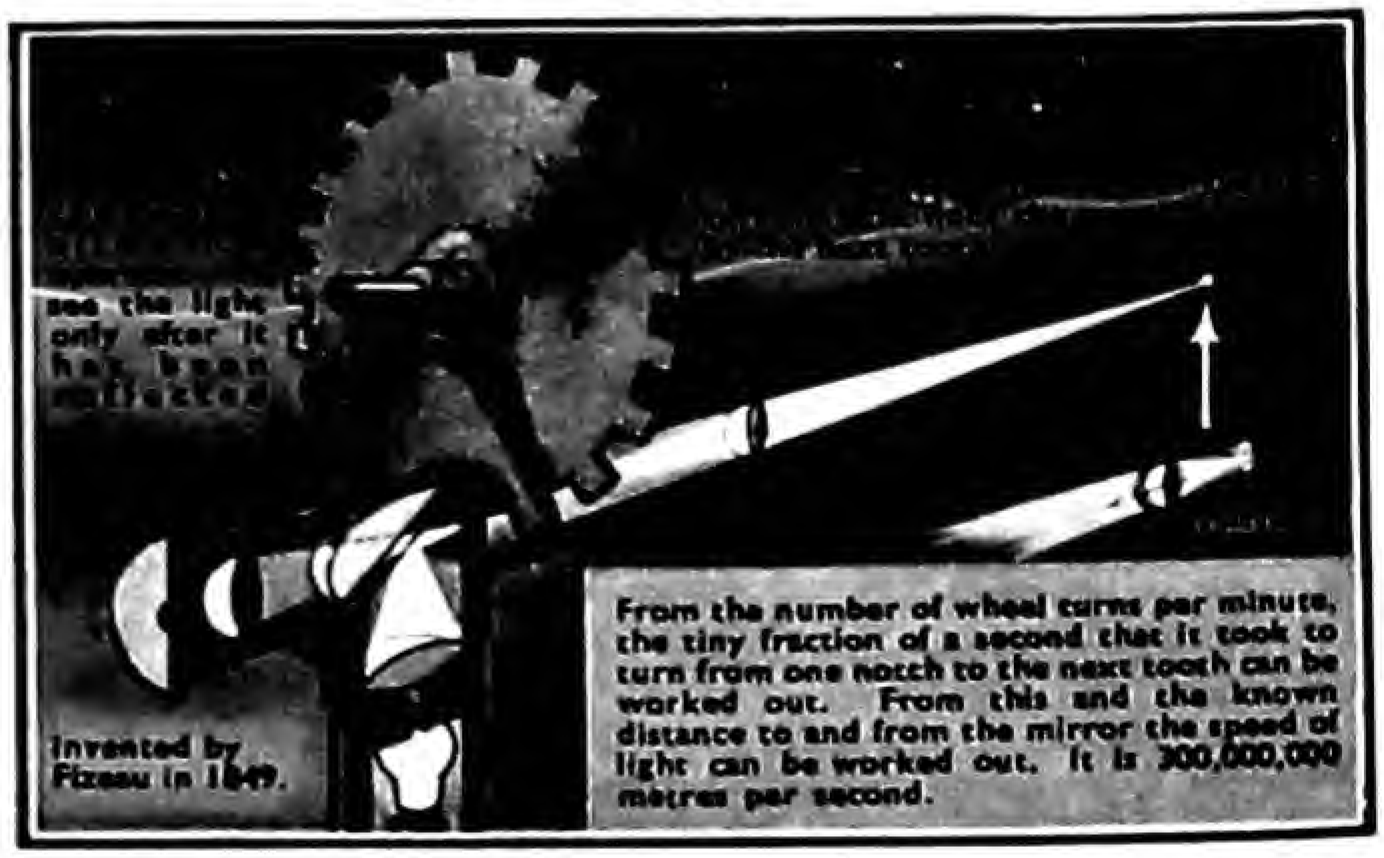
Unusual sorts of mirror which let one colour through, reflect others, split light rays in this TV camera into three vision signals to be broadcast together. The receiver puts each colour signal onto a separate electron beam in one viewing tube. Aimed at different angles through one hole of the shadow mask each electron beam strikes its own fluorescent spot that glows red, blue or green. Then the three beams move on to the next hole, and light up a fresh trio of spots.

Colour Printing

Because one opaque printing ink would hide the one below it, printers put tiny spots of ink of the three colours down beside each other, and vary the amount of each to give the illusion of mixed colours. Below is a full colour printing machine.

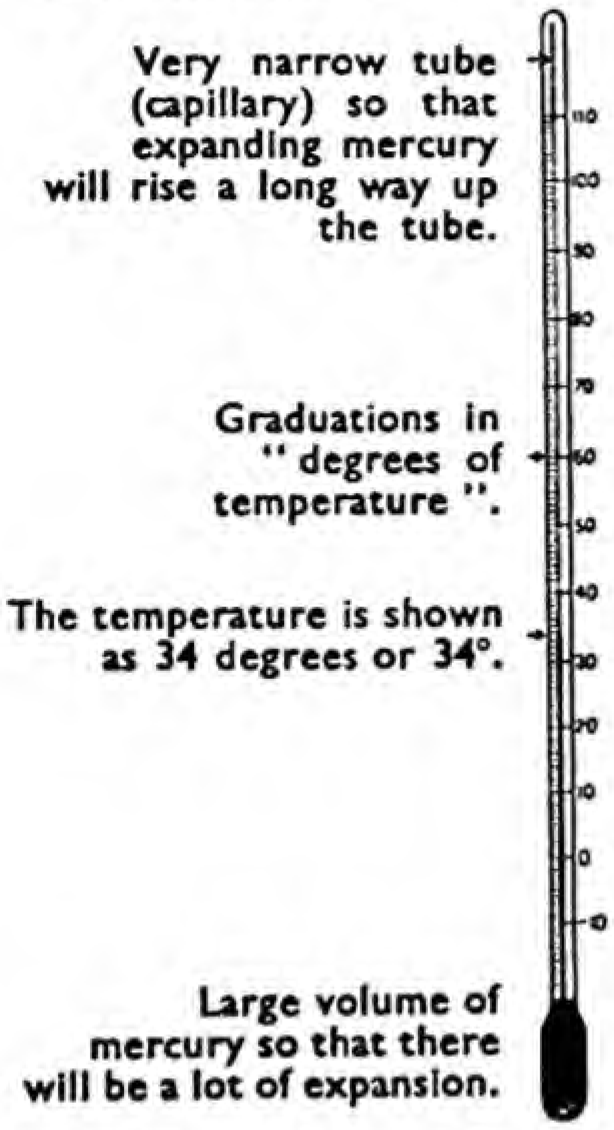


Measuring the Speed of Light

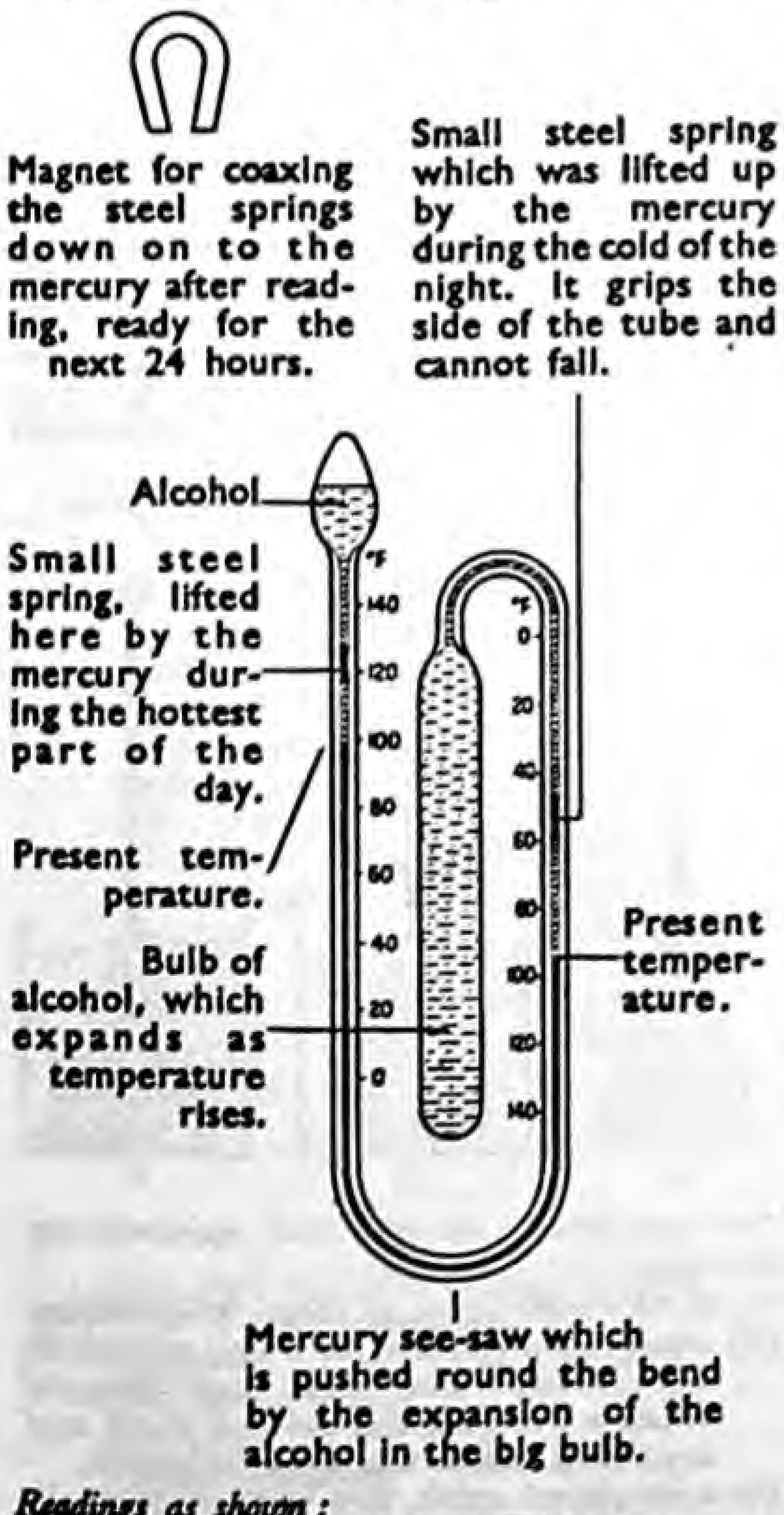


THE HEAT LAWS

A thermometer



A maximum and minimum thermometer for use in the greenhouse



Readings as shown:
The maximum temperature = 120°F.
The minimum temperature = 60°F.
The present temperature = 95°F.

TEMPERATURE is the degree of hotness. The hotter it is, the higher the temperature. Thermometers are used to measure temperature.

THERMOMETER SCALES

Scale	Freezing point of water	Boiling point of water	Number of degrees between F. Pt. & B. Pt.
Fahrenheit	32°F.	212°F.	180
Centigrade	0°C.	100°C.	100

Note: 180 : 100 = 18 : 10 = 9 : 5

Rule to convert Fahrenheit readings into Centigrade readings.

Example: 122°F.

Subtract 32 — $122 - 32 = 90$
Divide result by 9 — $90 \div 9 = 10$
Multiply result by 5 — $10 \times 5 = 50$
$\therefore$ 122°F. = 50°C.

Formula to convert Fahrenheit readings into Centigrade readings.

$$C = \frac{5(F - 32)}{9}$$

Example: 140°F.

$$C = \frac{5(140 - 32)}{9}$$
$$= \frac{5(108)}{9} = \frac{5 \times 12}{1}$$
$$= 60$$

$\therefore$ 140°F. = 60°C.

Rule to convert Centigrade readings into Fahrenheit readings.

Example: 70°C.

Divide by 5 — $70 \div 5 = 14$
Multiply result by 9 — $14 \times 9 = 126$
Add 32 — $126 + 32 = 158$
$\therefore$ 70°C. = 158°F.

Formula for changing degrees Centigrade into degrees Fahrenheit.

$$F = \frac{9C}{5} + 32$$

Example: 65°C.

$$F = \frac{9 \times 65}{5} + 32$$
$$= \frac{9 \times 13}{1} + 32$$
$$= 117 + 32 = 149.$$

65°C. = 149°F.

ABSOLUTE TEMPERATURE. It is believed that the lowest temperature that can be reached is approximately 273 Centigrade degrees below the freezing point of water, i.e. 0°C. − 273°C. = − 273°C. This is *absolute zero.* If we start counting from here, water freezes at 273° Absolute and boils at 373° Absolute (373°A.).

Rule for converting degrees Centigrade into degrees Absolute.

Add 273.

Example: 27°C.

$27 + 273 = 300.$
$\therefore$ 27°C. = 300°A.

Formula for converting degrees Centigrade into degrees Absolute.

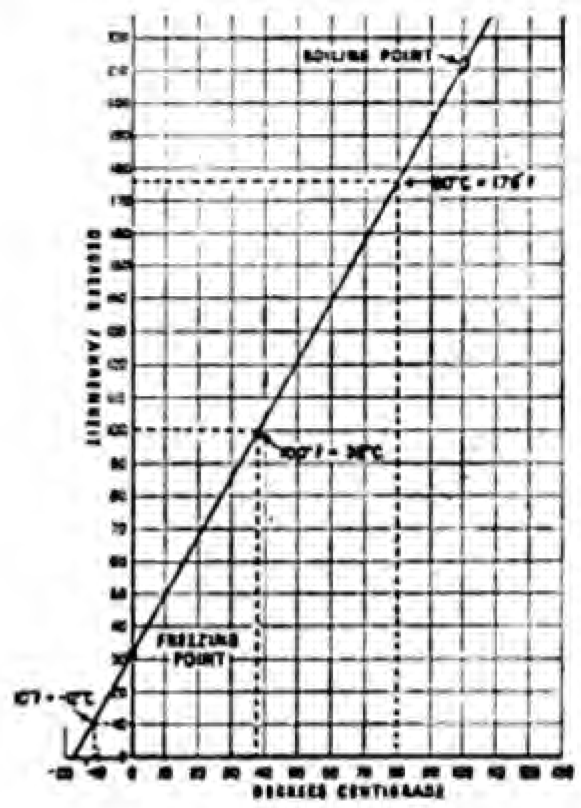
$A = C + 273.$

Example: 50°C.

$A = 50 + 273$
$= 323.$
$\therefore$ 50°C. = 323°A.

Note: Degrees Absolute are also called Degrees Kelvin, i.e. 323°K. = 323°A.

A graph to convert from Fahrenheit to Centigrade temperatures and vice versa



Reading the temperature of furnaces. Special methods are required for reading these temperatures which are too high for mercury thermometers. (a) *The optical pyrometer.* The operator looks at the open furnace through the pyrometer, which contains a special electric lamp and battery. The instrument is adjusted until the white-hot filament of the lamp is invisible against the background of the furnace. A scale on the pyrometer then tells the temperature. (b) *The thermo-couple pyrometer.* In this, two different metal alloy strips are joined together at one end. This end is exposed to the high temperature. The other ends, which stay cool, are connected to an electric meter which measures the tiny electric current set up by the action of heat on the junction. The dial can be marked to read the temperature of the furnace direct.

SOME INTERESTING TEMPERATURES

Average temperature of human body, in good health	98·4°F.
Dry ice (solid carbon dioxide)	−78° C.
Dull red heat	approx. 600°C.
Cherry red heat	,, 900°C.
White heat	,, 1,200°C.
Bunsen burner, blue flame, near top	,, 1,350°C.
Air turns to a liquid	,, −190°C.
Surface of the sun	,, 6,000°C.
Electric arc lamp	,, 3,500°C.
Electric lamp filament	,, 2,500°C.
Oxy-acetylene flame	,, 2,400°C.
Interior of sun: estimated	up to 40 million °C.

D

Expansion with rise in temperature. *The coefficient of linear expansion* is the increase in length of unit length for a rise in temperature of one degree.

CO-EFFICIENTS OF LINEAR EXPANSION, FOR 1°C.

Note. The co-efficient for 1°F is 5/9 as great in every case.

Aluminium	·000026
Brass	·000019
Copper	·000017
Steel	·000011
Concrete	·000012
Platinum	·000009
Glass	·0000085
Pyrex	·000003
Fused silica apparatus	·0000005
Invar (steel with 36% Nickel)	·0000009

These very small figures are difficult to visualise. Here they are again in another form, the increase in length of a rod *l mile* long for every 1°C. rise in temperature.

Aluminium	$1\frac{2}{3}$ inches
Brass	$1\frac{1}{5}$ inches
Copper	1 inch
Steel	$\frac{3}{4}$ inch
Concrete	$\frac{3}{4}$ inch
Platinum	$\frac{1}{2}$ inch
Glass	$\frac{1}{2}$ inch
Pyrex	$\frac{3}{16}$ inch
Fused silica apparatus	$\frac{1}{30}$ inch
Invar (steel with 36% nickel)	$\frac{1}{20}$ inch

Formula: l = original length; t = rise in temperature. α = co-efficient of linear expansion.

Expansion = $l \times \alpha \times t$ (α is pronounced "Alpha").

Example 1: A bridge, made of steel and 1,000 yards long has a minimum winter temperature of -10°C. and a maximum summer temperature of 40°C. What allowance must be made for expansion?

Expansion $= l \times \alpha \times t = 1{,}000 \times \cdot000011 \times 50$
$= 1 \times \cdot011 \times 50 = 1 \times \cdot11 \times 5$
$= \cdot55$ yds.

This is 1 ft. 8 in. approx.

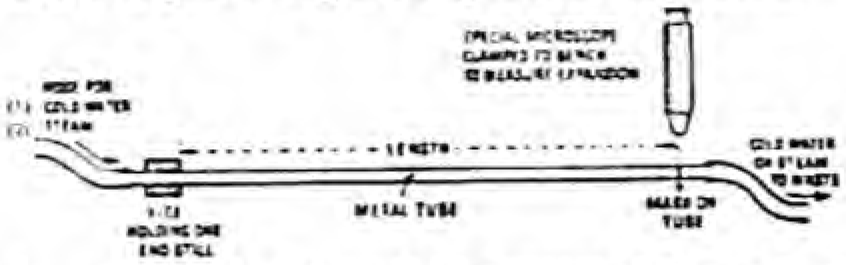
Example 2: It is intended to provide a steel tyre for an aluminium wheel (which is 100 in. across at 22°C.) so that the tyre will just fit the wheel when the latter is immersed in solid carbon dioxide at -78°C. The tyre will, of course, not be cooled down previous to fitting. What should be the diameter of the tyre?

The wheel is to be cooled down through 100 Centigrade degrees. Contraction of the wheel across its diameter

$= l \times \alpha \times t$
$= 100 \times \cdot000026 \times 100$
$= 1 \times \cdot0026 \times 100$
$= 1 \times \cdot26 \times 1 = \cdot26$ in.

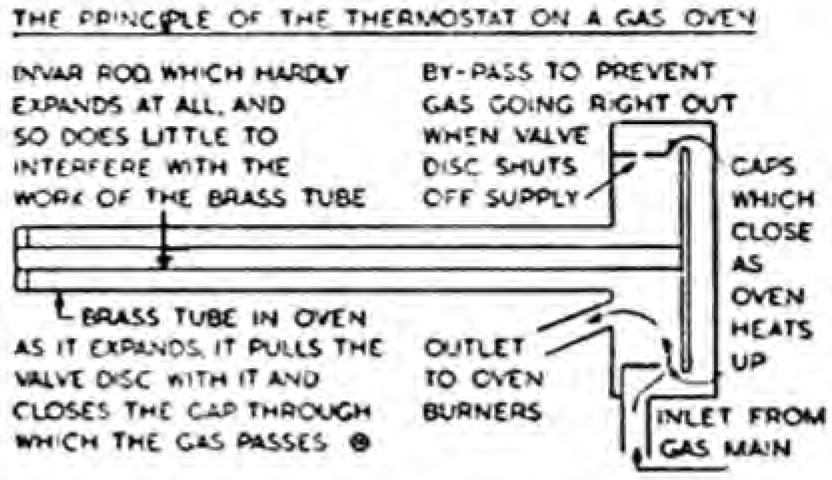
The tyre should have a diameter of 100 in. $-\cdot26$ in. $= 99\cdot74$ in.

Measuring the coefficient of linear expansion.



An expansion bend to prevent fracture of a long pipe which is sometimes cold and sometimes carries steam.

This distance is a little less when the pipe is hot.



The coefficient of superficial expansion is the increase in area of unit area for a rise in temperature of one degree.

Note: The coefficient of superficial expansion is *twice* the coefficient of linear expansion.

Example: The coefficient of linear expansion of aluminium is ·000026

∴ the coefficient of superficial expansion of aluminium is ·000052.

Formula:
A = original area
t = rise in temperature
β = coefficient of superficial expansion (β is pronounced "beta").
Increase in area $= A \times \beta \times t$.

Example: A sheet of brass is 5 sq. ft. in area at 10°C. What will be the area at 310°C.?

The coefficient of linear expansion of brass = ·000019

∴ coefficient of superficial expansion = ·000038.

Increase in area $= A \times \beta \times t$
$= 5 \times \cdot000038 \times 300$
$= \cdot057$ sq. ft.

Area of heated sheet $= 5$ sq. ft. $+ \cdot057$ sq. ft.
$= 5\cdot057$ sq. ft.

The coefficient of cubical expansion is the increase in volume of unit volume for a rise in temperature of one degree.

Note: For solids, the coefficient of cubical expansion is *three times* the coefficient of linear expansion.

Example: The coefficient of cubical expansion of aluminium is $3 \times \cdot000026 = \cdot000078$.

Formula:
V = Original volume
t = rise in temperature
γ = coefficient of cubical expansion (γ is pronounced "gamma").
Increase in volume $= V \times \gamma \times t$

Example: A steel ball has a volume of 100 cub. in. at 15°C. What will be its volume at 615°C.?

The coefficient of linear expansion of steel = ·000011

∴ the coefficient of cubical expansion of steel = ·000033.

Increase in volume $= V \times \gamma \times t$
$= 100 \times \cdot000033 \times 600$
$= 1\cdot98$ cub. in.

Volume at 615°C. $= (100 + 1\cdot98)$ cub. in.
$= 101\cdot98$ cub. in.

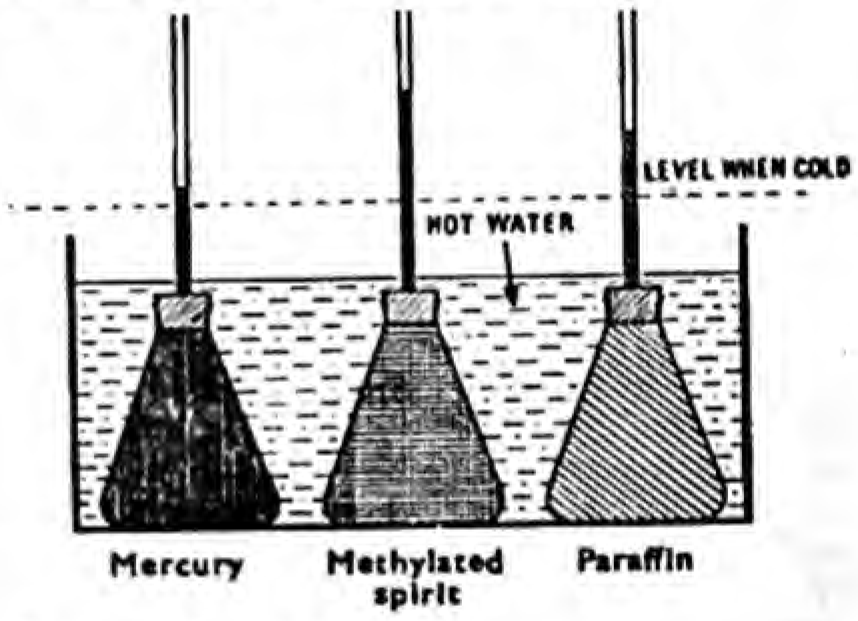
EXPANSION OF A LIQUID. Liquids appear to expand less than they really do, owing to the increase in size of the vessel which contains them.

The apparent coefficient of cubical expansion of a liquid is the one which is measured in a glass container.

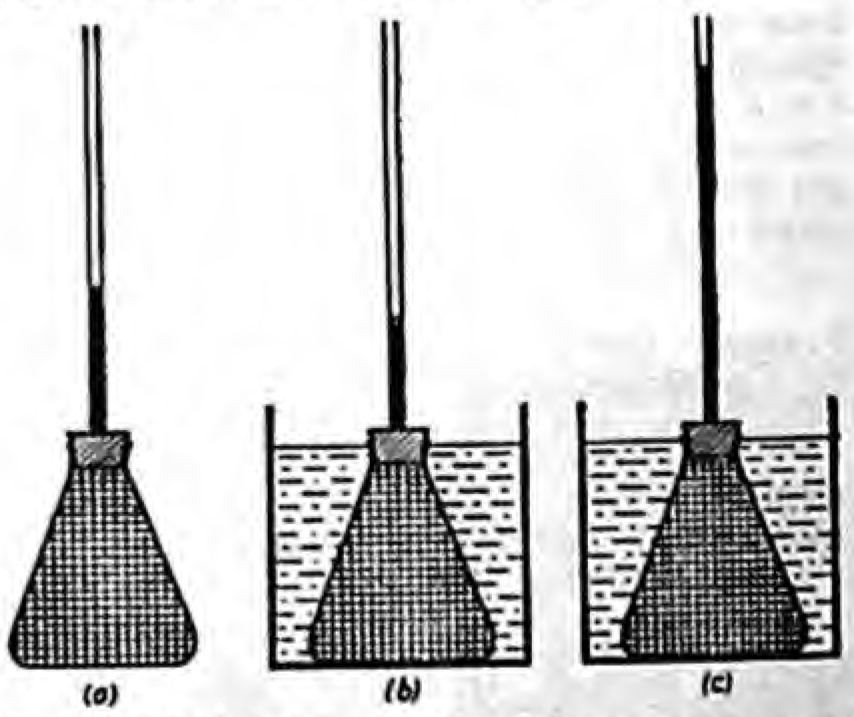
The real coefficient of cubical expansion is greater than this.

The real coefficient of cubical expansion of a liquid is the apparent coefficient of cubical expansion + the coefficient of cubical expansion of glass.

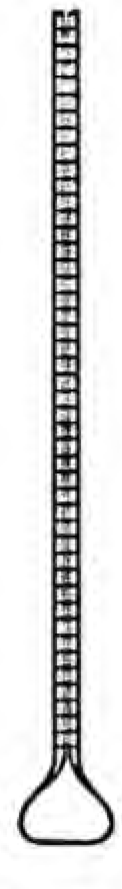
Example: The coefficient of cubical expansion of paraffin oil in a glass vessel is found to be ·0008745. The coefficient of cubical expansion of glass is ·0000255. The real coefficient of cubical expansion of paraffin is ·0008745 + ·0000255 = ·0009.



An experiment to show
(a) that expansion of a liquid is great enough to be seen with the naked eye.
(b) the different amounts liquids expand.



An experiment on real and apparent expansion:
(a) methylated spirit at room temperature.
(b) methylated spirit after a few seconds in hot water. The level has dropped because the flask has become warm and expanded before the liquid is heated.
(c) methylated spirit, five minutes later, in hot water. The spirit is now hot and its expansion is much greater than that of the flask.



A dilatometer, for finding coefficients of cubical expansion of liquids. This one is made of Pyrex, which expands so little that the result is almost a true "real coefficient".

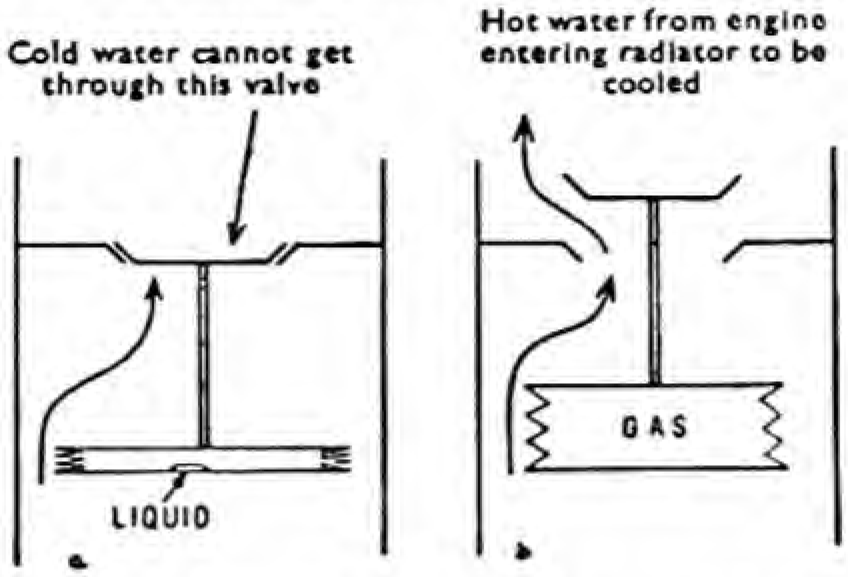
COEFFICIENTS OF CUBICAL EXPANSION OF LIQUIDS, PER CENTIGRADE DEGREE	
Methylated spirit	·0011
Turpentine	·0009
Mercury	·00018
Water (5°C.—10°C.)	·00005
,, (10°C.—20°C.)	·00015
,, (20°C.—40°C.)	·0003
Paraffin oil	·0009

The abnormal behaviour of water. The above table shows that water does not expand regularly, but at a greater rate as it is warmed up. Below 4°C., it *expands as it cools*. (See page 53.)

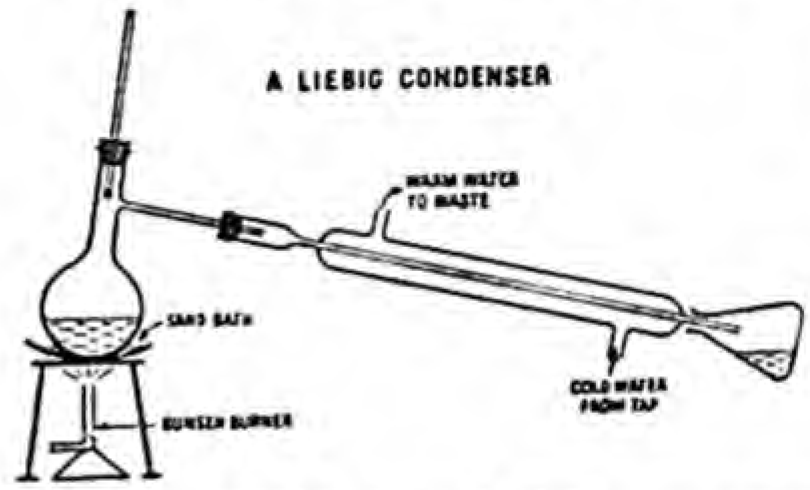
FREEZING POINTS, OR MELTING POINTS	
Water	0°C.
Mercury	−39°C.
Methylated spirit	−115°C.
Lead	327°C.
Iron (pure)	1527°C.
Cast iron (approx.)	1300°C.
Aluminium	660°C.
Copper	1083°C.
Oxygen	−219°C.
Platinum	1773°C.
Tungsten	3387°C.
Hydrogen	−259°C.

BOILING POINTS (under normal air pressure)	
Water	100°C.
Methylated spirit	78°C.
Mercury	357°C.
Liquid hydrogen	−253°C.
Lead	1755°C.
Liquid nitrogen	−196°C.
Liquid oxygen	−183°C.

A car radiator thermostat



(a) Engine is cold. The methylated spirit is a liquid and occupies a tiny space. Bellows are closed and valve shut. Water cannot circulate through radiator.
(b) Engine is hot. Methylated spirit is a gas and occupies a great space. Bellows are blown out, and valve is opened.



DISTILLATION. A method for separating liquids with different boiling points. The liquid of lower boiling point changes to gas, which passes into the condenser, where the cold-water jacket changes it back to liquid, which is collected. The liquid of higher boiling point is unchanged. The thermometer reads the temperature of the vapour coming over.

QUANTITY OF HEAT

THE CALORIE is the quantity of heat required to raise the temperature of 1 gramme of water through 1°C. It is also the quantity of heat given out when 1 gramme of water cools through 1°C.

THE BRITISH THERMAL UNIT (B.Th.U.) is the quantity of heat required to raise the temperature of 1 lb. of water through 1°F. It is also the quantity of heat given out when 1 lb. of water cools through 1°F.

SPECIFIC HEAT is the quantity of heat taken in or given out when unit mass of the substance changes its temperature by one degree.

Example 1: 1 gm. of water needs 1 calorie to raise its temperature 1°C.

$\therefore$ its specific heat is 1.

Example 2: 1 lb. of water needs 1 B.Th.U. to raise its temperature 1°F.

$\therefore$ its specific heat is 1.

Example 3: 1 gm. of aluminium gives out ·21 calories of heat on cooling through 1°C.

$\therefore$ the specific heat of aluminium is ·21.

SPECIFIC HEATS (calories or B.Th.U.)			
Aluminium	·21	Solder	·04
Brass	·09	Water	1·0
Copper	·09	Methylated spirit	·55
Gold	·03	Paraffin oil	·51
Iron	·10	Sea water	·94
Lead	·03	Air	·24
Mercury	·03	Hydrogen	3·42

THERMAL CAPACITY is the heat required to raise the temperature of an object by one degree. It is mass × specific heat.

Example:
(a) The thermal capacity of 1,000 gm. of copper $= 1{,}000 \times \cdot 09 = 90$ calories per °C.
(b) The thermal capacity of 100 gm. of water $= 100 \times 1 = 100$ calories per °C.
(c) The thermal capacity of 10 lb. of lead is $10 \times \cdot 03 = \cdot 3$ B.Th.U. per °F.

THE METHOD OF MIXTURES. A known mass of one substance, of known temperature and specific heat, is added to a known mass of another substance, also of known temperature. The mixture is stirred, its temperature taken and the unknown specific heat calculated.

Equation: Heat lost by one substance = heat gained by the other.

Mass × specific heat × fall in temperature = mass × specific heat × rise in temperature.

Example 1: 20 gm. of metal of specific heat ·1 are heated to 100°C. and dropped into 100 gm. of a liquid at 15°C. The temperature of the mixture is 20°C. What is the specific heat of the liquid?

Heat lost by metal

= Heat gained by liquid

$$\therefore 20 \times \cdot 1 \times (100-20) = 100 \times s \times (20-15)$$
$$\therefore 20 \times \cdot 1 \times 80 = 100 \times s \times 5$$
$$\therefore 160 = 500s$$
$$\therefore s = \frac{160}{500} = \frac{32}{100} = \cdot 32.$$

Example 2: 100 gm. of a metal at 80°C. are dropped into 250 gm. of water at 20°C. The mixture has a temperature of 30°C. Calculate the specific heat of the metal.

Heat lost by metal = Heat gained by water

$$\therefore 100 \times s \times (80-30) = 250 \times 1 \times (30-20)$$
$$\therefore 10\cancel{0} \times s \times 50 = 25\cancel{0} \times 1 \times 1\cancel{0}$$
$$\therefore 50s = 25$$
$$\therefore s = \cdot 5$$

CALORIFIC VALUE. The calorific value of a solid or a liquid is the amount of heat given out when unit mass of the fuel is completely burnt. For example, the calorific value of a good quality coal is about 14,500 B.Th.U. per lb., or about 8,000 calories per gm. For coke, the value is about 7,000 calories per gm. (12,600 B.Th.U. per lb.), for wood about 4,000 calories per gm. (7,250 B.Th.U. per lb.) and for paraffin oil 9,800 calories per gm. (17,600 B.Th.U. per lb.).

The calorific value of coal gas is stated in B.Th.U. per cubic foot, e.g. 500 B.Th.U. per cubic foot. Coal gas is sold by the *Therm*—100,000 B.Th.U. of heat.

Example: The December reading of a gas-meter = 20,600 cub. ft.

The September (previous) reading = 18,200 cub. ft.

Gas consumed = 2,400 cub. ft.

Calorific value = 500 B.Th.U. per cubic foot of gas.

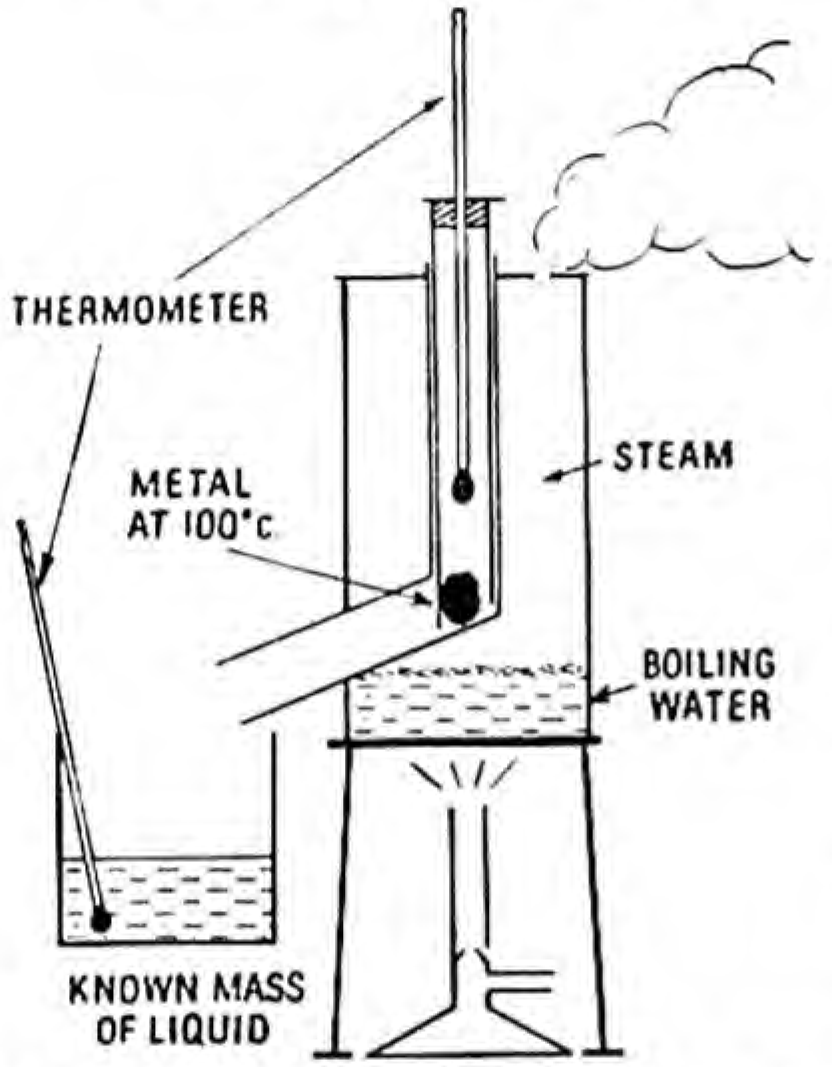
$\therefore$ heat supplied on burning gas = 2,400 × 500 B.Th.U.

$= \frac{2,400 \times 500}{100,000}$ Therms = 12 Therms.

Cost per therm = 1*s*. 9*d*.

Cost for 12 therms = 12 × 1*s*. 9*d*.
= £1 1*s*. 0*d*.

A specific heat experiment



The inner tube, carrying the thermometer, is a sliding fit inside the outer tube. On lifting the inner tube, the hot solid slides down the chute into the cold liquid.

CHANGE OF STATE (a) from solid to liquid
(b) from liquid to gas

Heat has to be supplied to change ice at 0°C. into water at 0°C. As there is no rise in temperature when this heat is supplied, it is known as Latent Heat (of fusion).

Heat is also required to change water at 100°C. into steam at 100°C.—Latent Heat of evaporation.

The Latent Heat of fusion of ice is 80 calories per gm. (144 B.Th.U. per lb.). The Latent Heat of evaporation of water = 538 calories per gm. (968 B.Th.U. per lb.).

Calculation 1: 20 grammes of dry ice are added to 100 grammes of water at 22°C. When the ice has melted the temperature of the mixture is 5°C. Calculate the latent heat of ice. L = latent heat of ice.

Heat given out by water cooling from 22°C. to 5°C. = heat gained by ice melting + heat gained by water formed warming from 0°C. to 5°C.

$\therefore 100 \times 1 \times (22-5)$ calories
$= 20 \times L + 20 \times 1 \times (5-0)$ calories

$\therefore 100 \times 17 = 20L + 20 \times 5$

$\therefore 1,700 = 20L + 100$

$\therefore 1,700 - 100 = 20L$

$\therefore 1,600 = 20L$

$\therefore 80 = L$

Latent heat of ice = 80 cal. per gm.

Calculation 2: 2 gm. of dry steam at 100°C. are bubbled into 60 gm. of water, raising the temperature from 20°C. to 40°C. Find the latent heat of steam. L = latent heat of steam.

Heat given out by steam condensing + heat given out by water formed cooling from 100°C. to 40°C. = heat gained by original water being warmed from 20°C. to 40°C.

$\therefore 2 \times L + 2 \times 1 \times (100 - 40)$
$= 60 \times 1 \times (40 - 20).$

$\therefore 2L + (2 \times 60) = 60 \times 20$

$\therefore 2L + 120 = 1,200$

$\therefore 2L = 1,200 - 120$

$= 1,080$

$\therefore L = 540$

The Latent Heat of steam (also of evaporation of water) = 540 cal. per gm.

Evaporation can occur at temperatures lower than the boiling point.

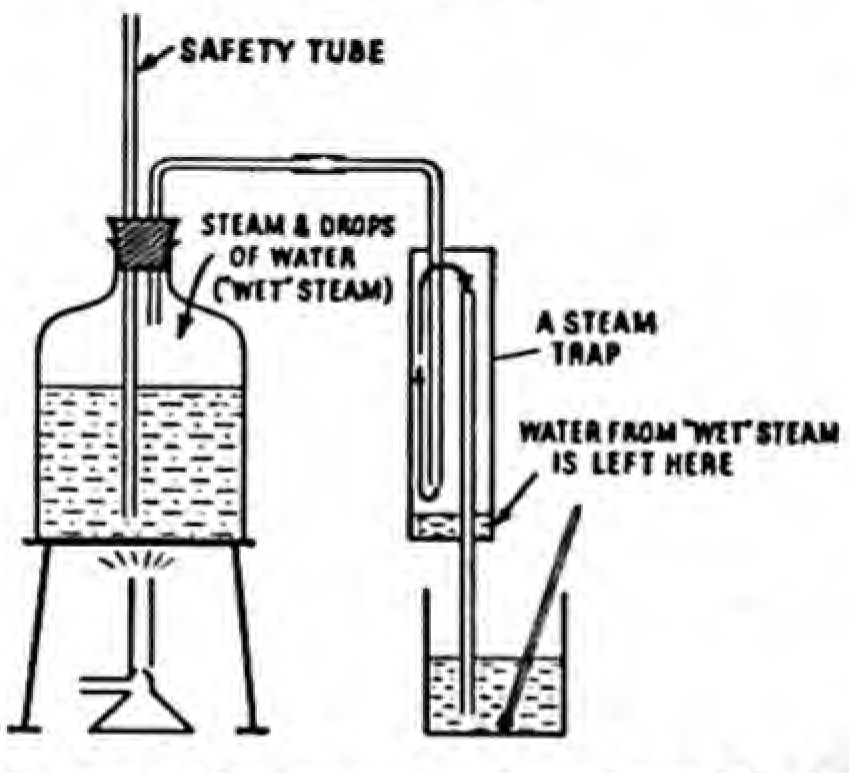
Latent Heat must be supplied to change a liquid into a gas. If it is not specially supplied, e.g. by a burner, it is taken from the body itself or the surroundings by lowering the temperature.

Example 1: Human beings perspire when too hot, so that the beads of perspiration may evaporate, take latent heat from the body and cool it.

Example 2: Butter dishes and milk bottles may be kept cool by wrapping them in a damp cloth from which water evaporates, taking the latent heat from the butter dish or milk bottle.

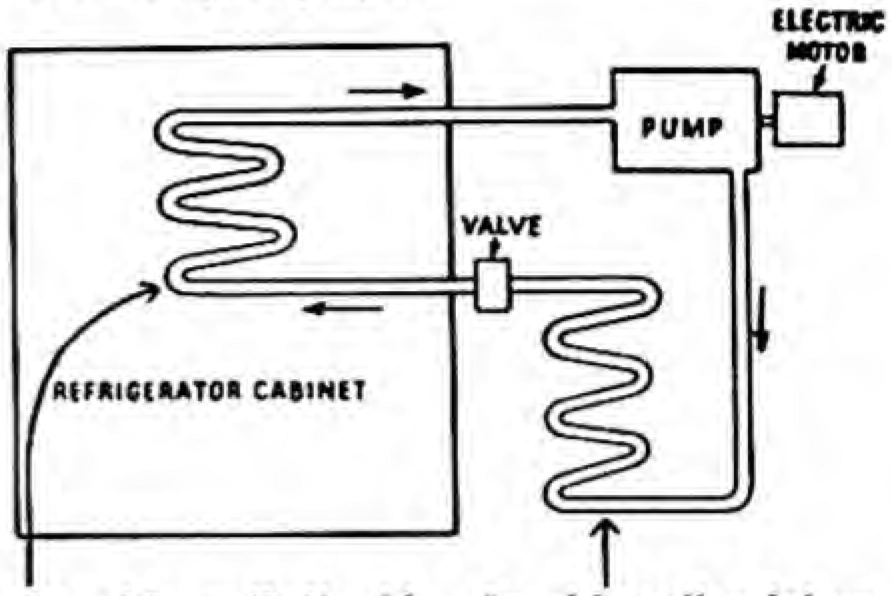
Example 3: It is unwise to keep on clothes which have become wet, because water will evaporate and take the latent heat from the body, thus causing a chill.

An experiment to find the "latent heat of steam"



The mass of steam used is found by weighing, before and after the experiment, the vessel in which the steam warms the water.

AN IMPORTANT USE OF LATENT HEAT. Sulphur dioxide (latent heat = 96 calories per gm.) is one of the liquids commonly employed.



In this coil liquid sulphur dioxide evaporates, needing 96 calories for every gramme changing from liquid to gas. This latent heat is taken from the contents of the refrigerator, cooling them down.

In this coil sulphur dioxide gas changes, under pressure, to liquid, giving out to the air 96 calories for every gramme changed.

The valve keeps the pressure high in the exterior coil (the radiator) and low in the interior coil.

Note: The air around the refrigerator is warmed by the latent heat of condensation of the sulphur dioxide—the inside of the refrigerator is cooled down by the latent heat of evaporation of the same substance.

TRANSFER OF HEAT

CONDUCTION. Heat passes from point to point in a substance without the substance itself moving; for example, along a poker left in a hot fire.

Good conductors of heat: silver, copper, aluminium.

Poor conductors of heat: glass, wood, cork, asbestos.

Uses for good conductors: copper for boilers, aluminium for saucepans.

Uses for bad conductors: asbestos for fire-fighting suits, wool for blankets, plastics for saucepan handles.

CONVECTION. This is the movement of heat, through the setting up of currents in a liquid or gas, owing to the expansion and consequent decrease in density of the substance in contact with the source of heat.

Useful applications of convection currents:

In air: ventilation of rooms, supply of air to fireplaces and boilers, warming rooms.

In water: hot-water systems, the cooling of a motor-car engine.

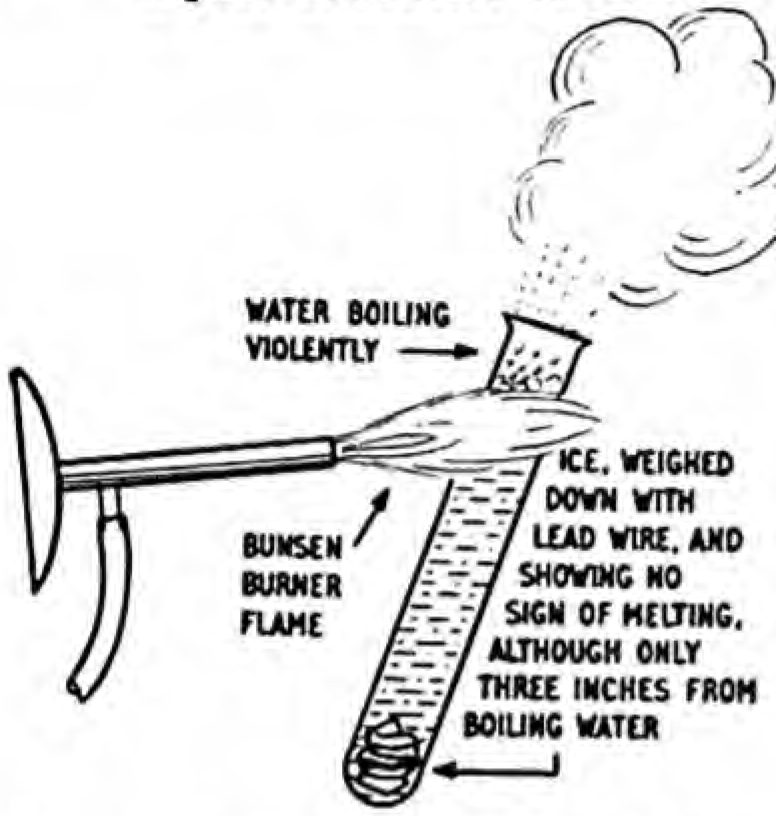
RADIATION. Heat waves, which can travel through empty space; for example, radiated heat received from the sun. Cool bodies radiate very little heat; intensely hot bodies radiate a lot.

The heat radiated by a body is proportional to the fourth power of the absolute temperature; for example, the heat radiated at 2,730°K. (2,457°C.) is 10 × 10 × 10 × 10 times that radiated at 273°K. (0°C.), i.e.

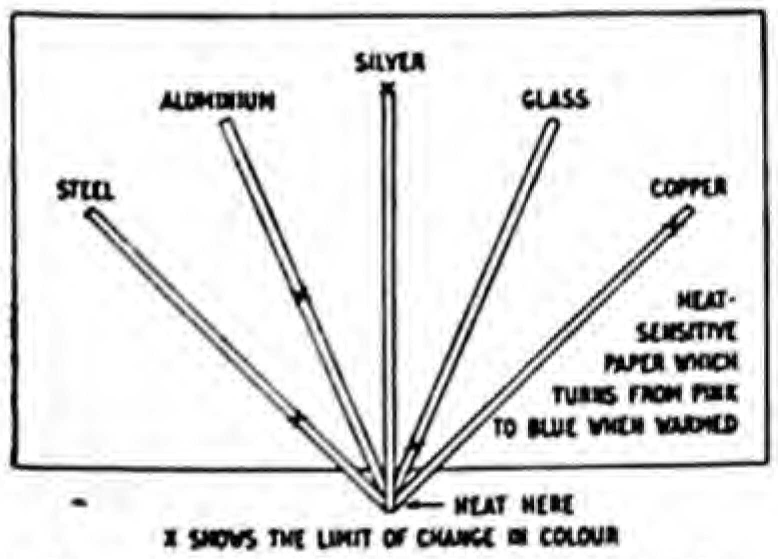
10,000 times as much. Black surfaces radiate more heat than white ones, and dull surfaces radiate heat better than highly polished ones. Radiated heat is absorbed best by dull black surfaces and least by white and highly polished ones.

The polished reflector behind an electric heating element reflects radiated heat into a room just as the reflector of a searchlight reflects a beam of light. In countries where sunshine is regular, steam may be raised by reflecting the sun's rays on to a boiler by means of huge mirrors.

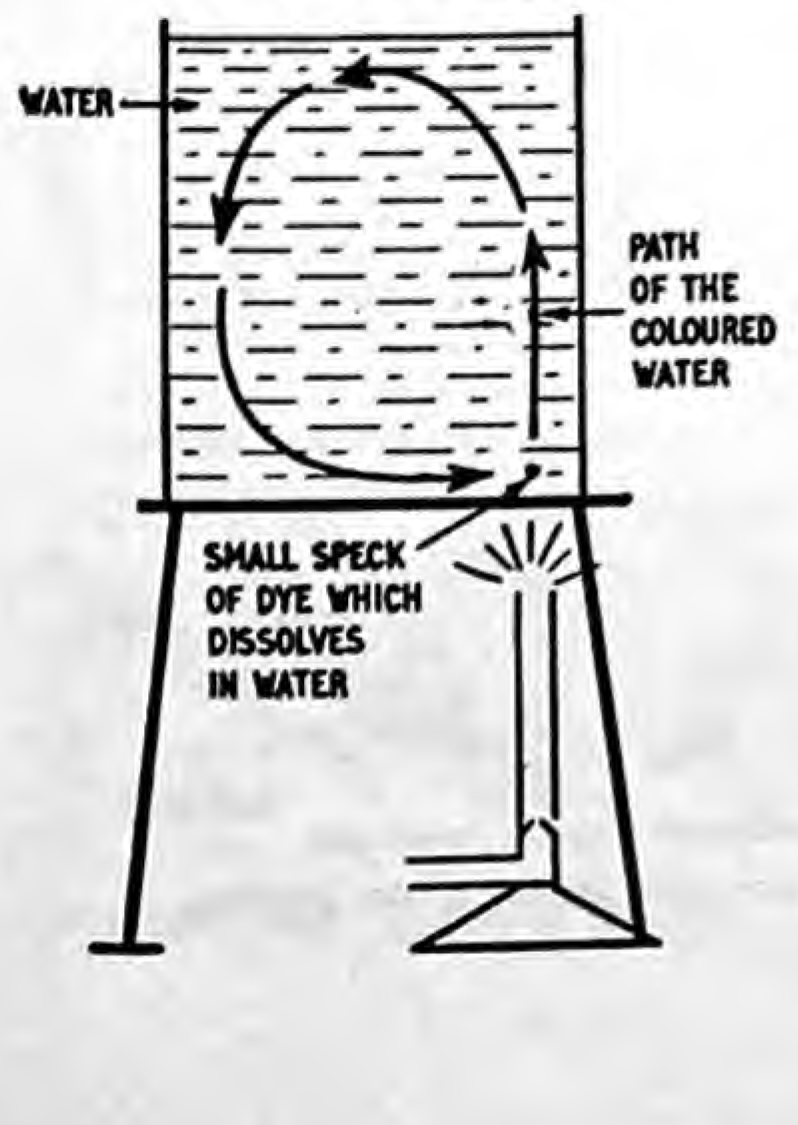
An experiment to show that water is a poor conductor of heat



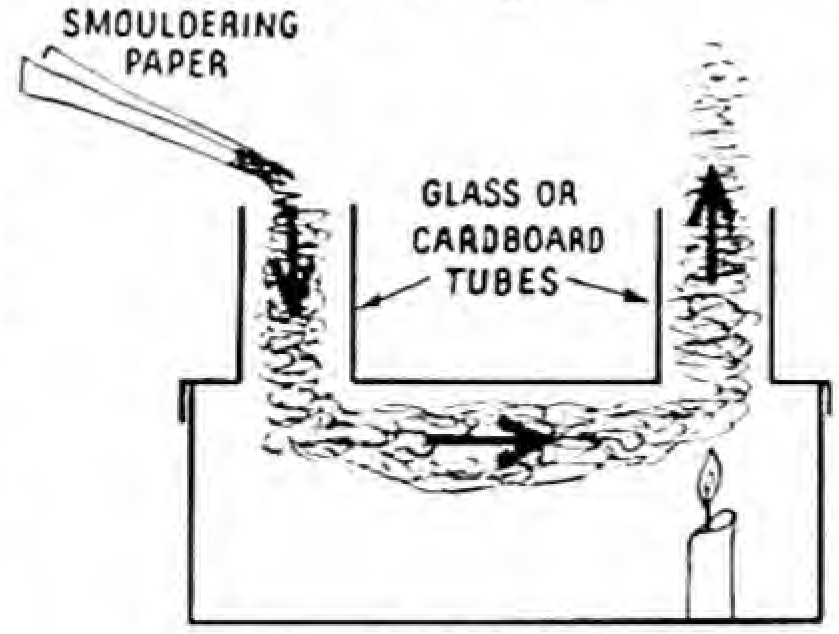
An experiment to compare the conductivities of common substances in the form of rods



An experiment to show convection currents in a liquid

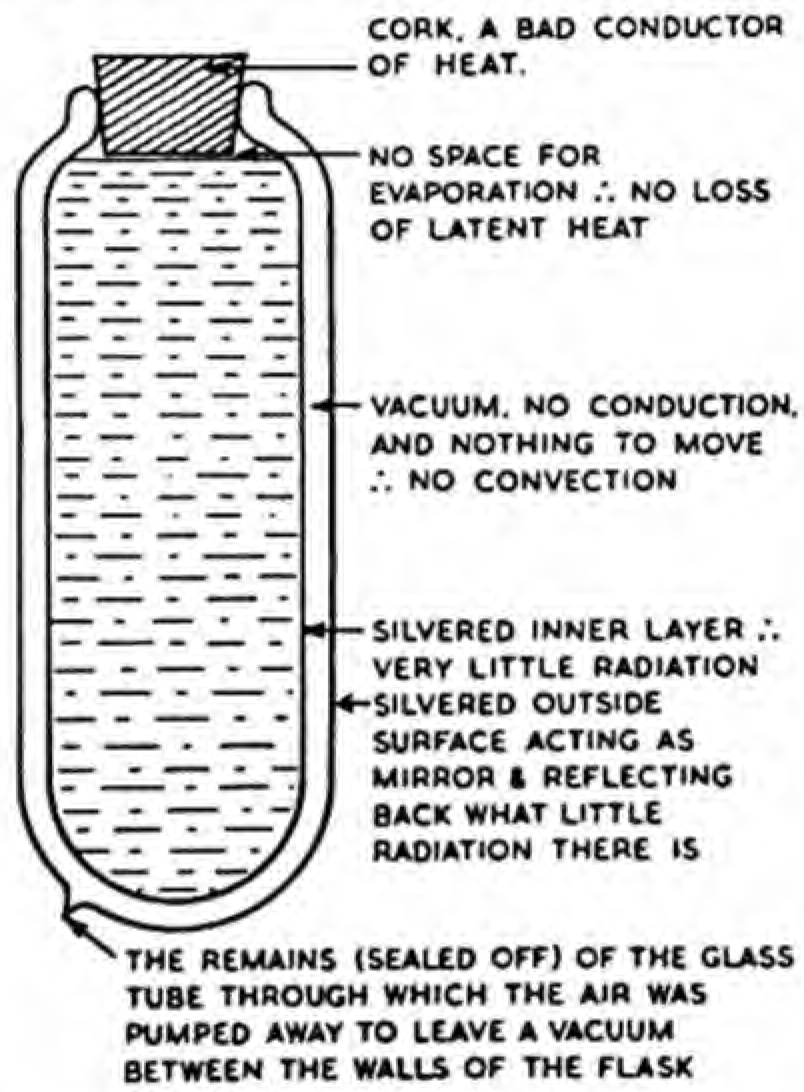


An experiment to show convection currents in a gas



The Thermos Flask

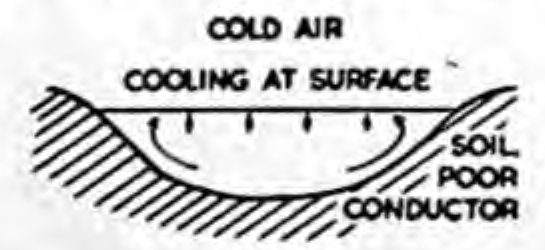
All losses of heat are reduced to the minimum, so liquids remain hot for long periods.



A vacuum flask will keep tea or soup hot for at least 24 hours. Since it is just as difficult for heat to pass into the flask from outside as it is for heat to be lost from the inside, the vacuum flask may be used to keep iced drinks cold. This it will do for many days. In the case of the iced drink, the difference in temperature between the contents and the outside air is much less than in the case of the hot drink, hence the longer period of time for which the flask is effective.

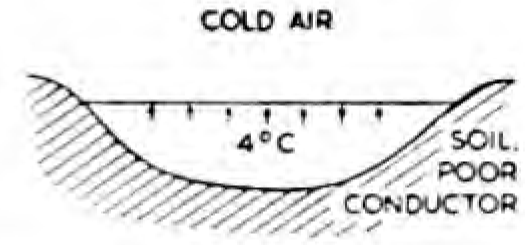
The odd behaviour of water, which results in a thin layer of ice on a pond with moderately warm water left beneath it.

Stage 1: Until water reaches 4°C.



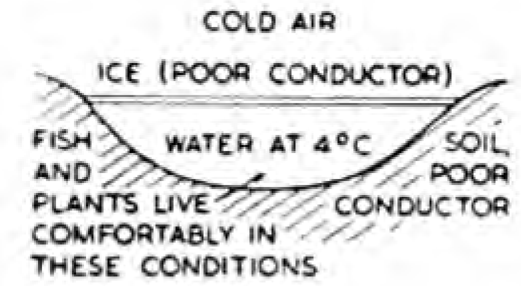
Water contracts, becomes denser, and sinks. Water from the bottom is forced up by descending cold water, and is cooled. All water is cooled down rapidly.

Stage 2: When 4°C. is reached.



The water *expands* on cooling, becomes less dense and stays on top, protecting water below it from contact with the cold air.

Stage 3:



SOME FREEZING MIXTURES

Parts by weight	*Temperature reached*
Melting ice or snow	0°C.
2 of crushed ice or snow, 1 of common salt	−18°C.
3 of snow, 4 of calcium chloride crystals	−48°C.
1 of ammonium nitrate crystals, 1 of water	−15°C.

THE EFFECT OF PRESSURE ON THE BOILING POINT OF WATER

Pressure in atmospheres, i.e. compared with normal air pressure on Earth's surface	*Boiling point*
normal	100°C.
½ normal	81°C.
¼ normal	65°C.
1/10 normal	46°C.
2 normal	121°C.
4 normal	145°C.
8 normal	171°C.
100 normal	310°C.

PRESSURE COOKERS. In a domestic pressure cooker working at 2 atmospheres, food is cooked at 121°C. instead of at 100°C., much time being saved.

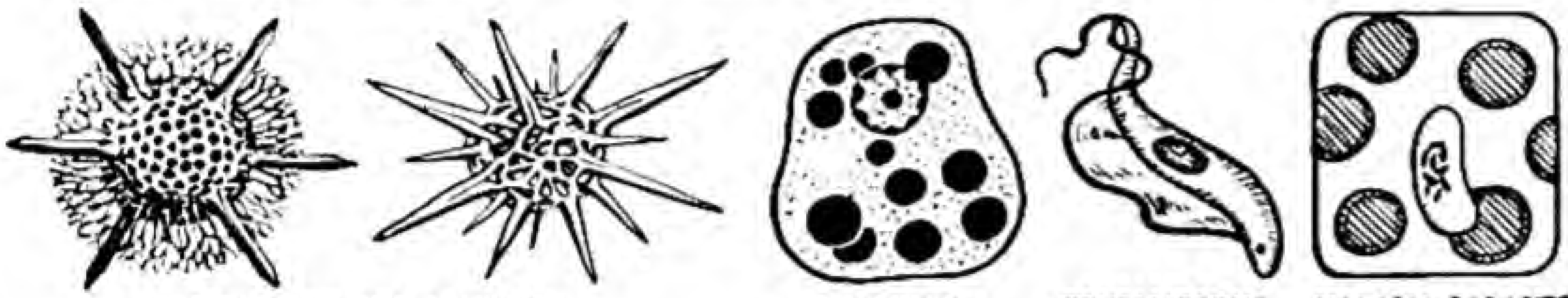
THE FAMILY OF LIVING CREATURES

Invertebrates

Protozoa

AMOEBA PARAMECIUM VORTICELLA FORAMINIFERAN AND SKELETON

Live in water or as parasites. All necessary functions carried out in one microscopic unit of protoplasm (cell). Resist drying up by

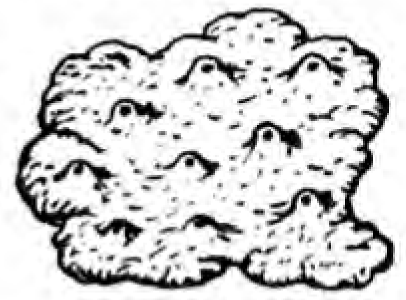


RADIOLARIAN AND SKELETON ENTAMOEBA TRYPANOSOME MALARIA PARASITE

encystment (withdrawal into walled capsule). Distributed like dust when encysted.

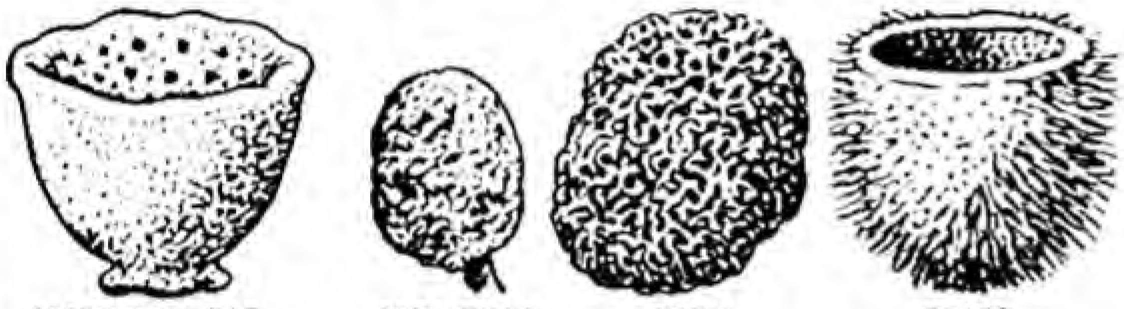
Sponges

Many celled, hollow and porous colonies



CRUMB O' BREAD

with chalky, sandy or horny stiffening material.



ELEPHANTS EAR SPONGILLA BATH GLASS

Reproduce by means of fertilised eggs or by budded off gemmules.

Coelenterates

HYDRA OBELIA SEA FIR

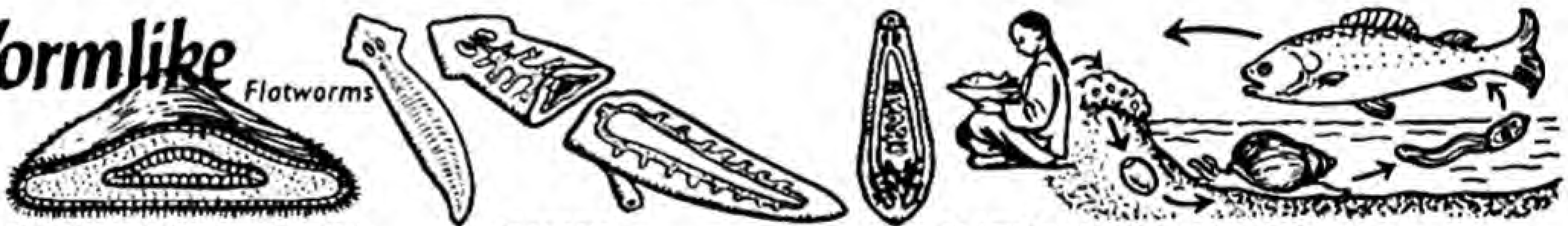
Polyps and jellyfish. Many celled. Body wall of two cell layers.

PORTUGUESE MAN O' WAR JELLYFISH CASSIOPEA SECTION THROUGH CORAL SEA ANEMONE SEA GOOSEBERRY

Stomach is only body cavity. Some colonial, such as corals, and develop horny or stony skeletons.

Worms and Wormlike Animals

Bodywall of three cell layers.

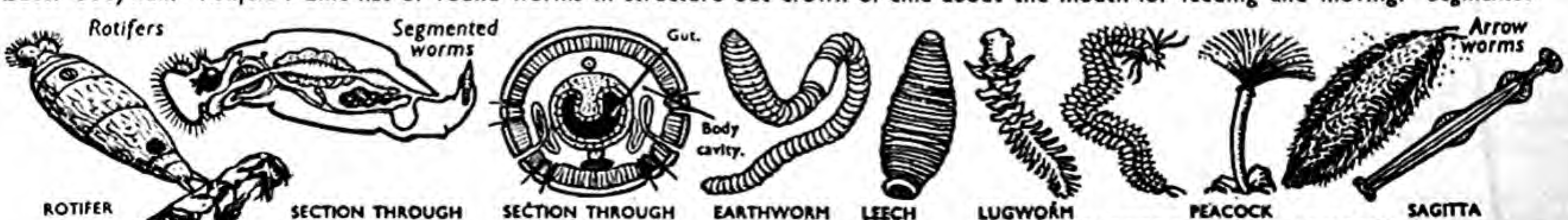


SECTION THROUGH FLATWORM PLANARIA CHINESE LIVERFLUKE AND LIFE CYCLE

Body elongated. *Flatworms* : Gut is only body cavity. Some are parasites. *Round worms* : Have fluid filled cavity between intestine and

HEAD AND SEGMENT OF TAPEWORM LIFE CYCLE OF TAPEWORM SECTION THROUGH ROUNDWORM ASCARIS HOOK WORM FILARIA

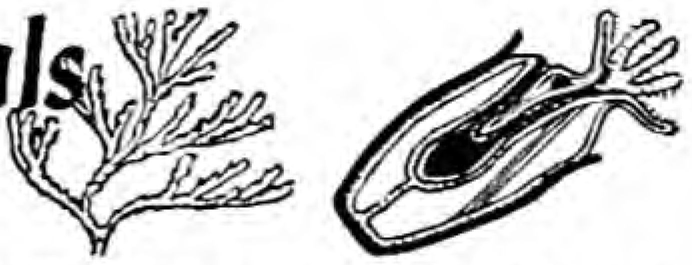
outer bodywall. *Rotifers* : Like flat or round worms in structure but crown of cilia about the mouth for feeding and moving. *Segmented*



ROTIFER SECTION THROUGH ROTIFER SECTION THROUGH EARTHWORM EARTHWORM LEECH LUGWORM RAGWORM PEACOCK WORM APHRODITE SAGITTA

worms : Body in segments. True body cavity between gut and body wall. *Arrow-worms* : Simple wormlike animals of the plankton.

Moss Animals

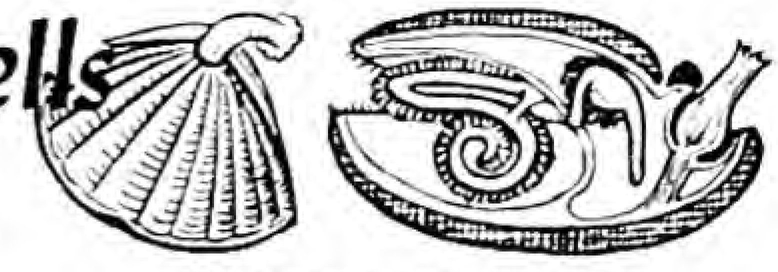


Plant-like appearance.

FLUSTRA COLONY BRYOZOAN INDIVIDUAL

Colonies of polyp-like creatures with true body cavity.

Lamp Shells



Animal between upper

TEREBRATULA AND STRUCTURE

and lower shell, hinged at tail end from which emerges foot stalk.

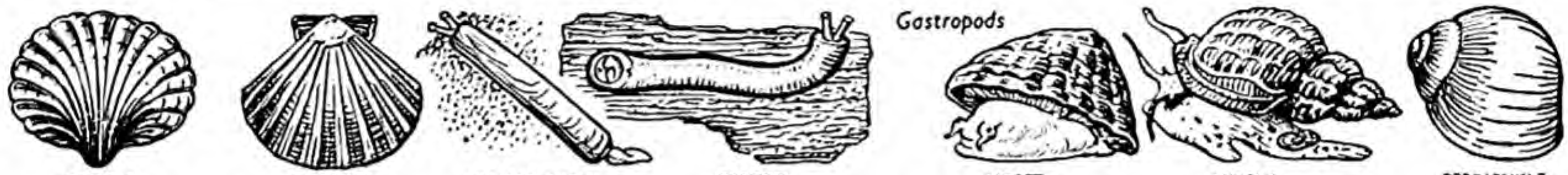
Molluscs

Bivalves

CHITON AND STRUCTURE CLAM OYSTER MUSSEL

Soft, unsegmented bodies. Usually with shell of lime salts secreted by a mantle. *Chiton* : Has shell of eight overlapping plates.

Gastropods



COCKLE SCALLOP RAZOR SHELL TEREDO LIMPET WHELK PERIWINKLE

Bivalves : Have two shells each sideways to animal. Foot for digging. Feeding by water flow through in and out siphons at hind end.

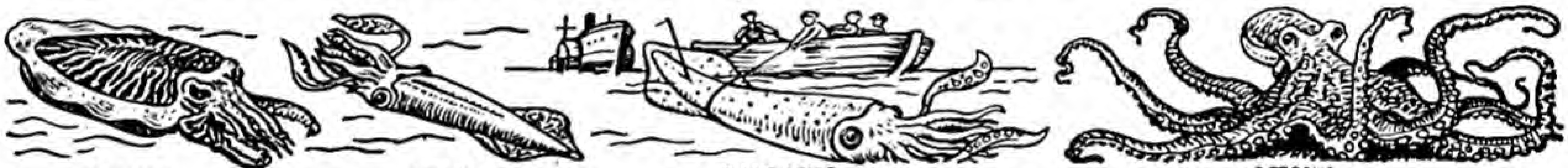
Tiny shell.

SNAIL TESTACELLA SLUG LIMAX SLUG PLUMED SEA SLUG

Cephalopods

NAUTILUS AND SHELL

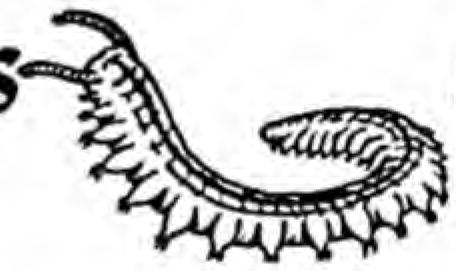
Gastropods : Distinct head, bearing tentacles. Foot flattened for crawling. Gut bearing portion and shell often spirally twisted.



CUTTLEFISH SQUID GIANT SQUID OCTOPUS

Cephalopods : Head greatly developed and with tentacles. Shell usually reduced and often internal. Complex eyes.

Simple Claw Bearers

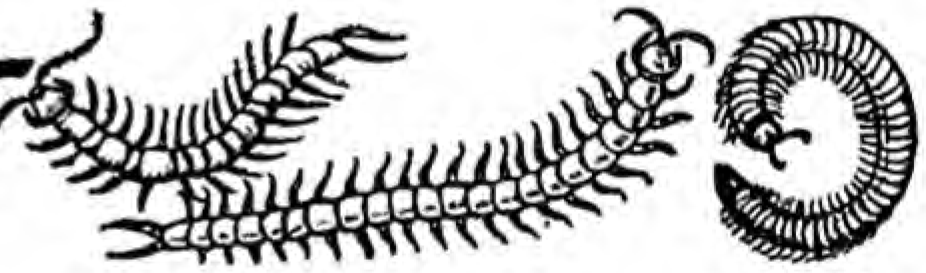


Combines character of segmented

PERIPATUS

worms and joint legged arthropods. Paired legs.

Myriapods

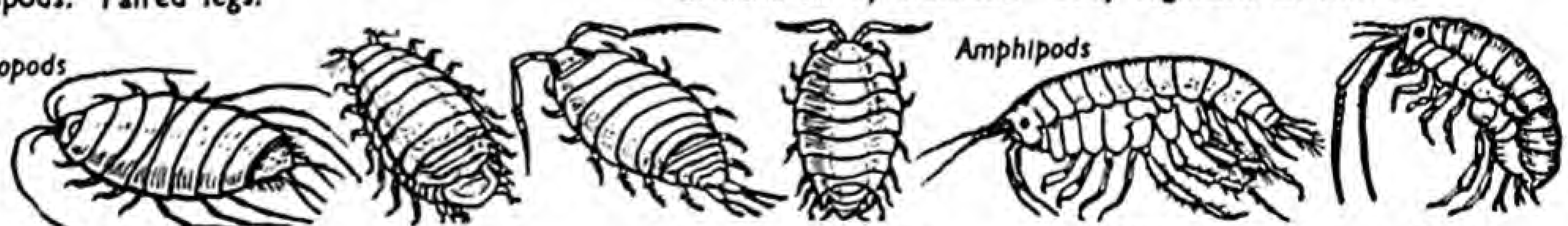


CENTIPEDES MILLIPEDE

Breathe air by tracheae. Body segments all similar.

Crustacea

Isopods *Amphipods*



ASELLUS LIMNORIA LIGIA PORCELLIO GAMMARUS PULEX TALITRUS

Chiefly aquatic, breathe by gills. Two pairs of antennae. Three pairs of head legs act as jaws. *Isopods* : Flattened top and bottom.

Decapods *Branchipods*

CRAYFISH LOBSTER PRAWN SHRIMP CRAB HERMIT CRAB FAIRY SHRIMP DÁPHNIA

Amphipods : Body compressed sideways. *Decapods* : Breastplate covers thorax. *Branchipods* : Limbs flattened and gill like.

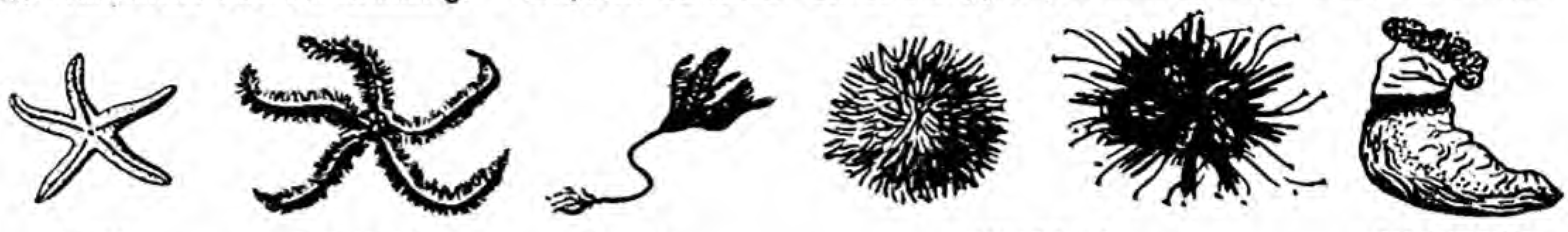
Copepods

CYCLOPS CALANUS BALANUS

Arachnida	**Insecta**
Spiders etc. Usually two divisions of body. Four pairs of legs. See *page* 212.	Three divisions of body. Three pairs of legs. See *pages* 209–212.

Copepods: No breastplate. Antennules used for swimming. *Cirripedes:* Barnacles. Larvae are typically crustacean though adults are shelled.

Echin–oderms



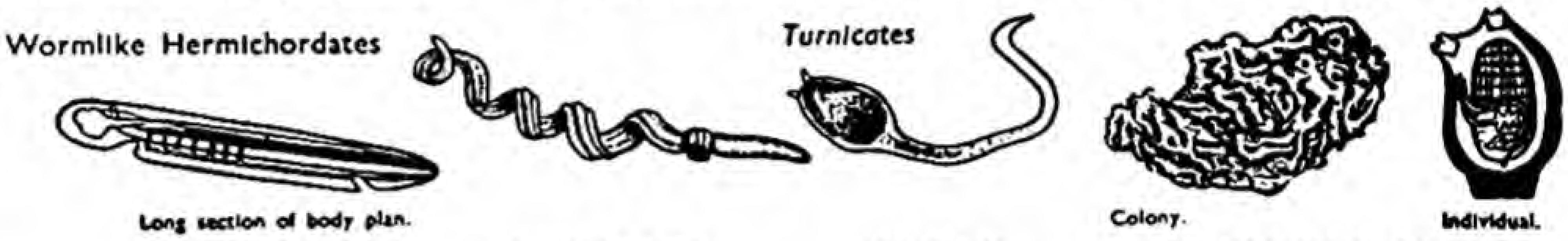
STARFISH BRITTLESTAR SEA LILY SEA URCHINS SEA CUCUMBER

Echinoderms: True body cavity divided into several compartments. Chalky skeleton as plate within body wall. Adults usually five rayed.

Vertebrates

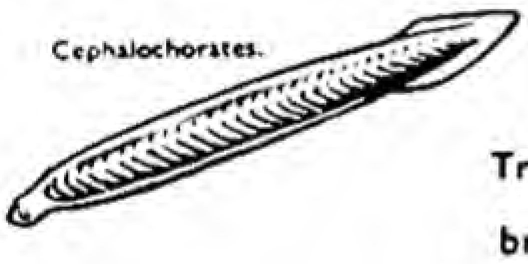
Acraniata

Wormlike Hermichordates *Turnicates*



BALANOGLOSSUS SEA SQUIRT GOOSEBERRY SQUIRT

Wormlike Hermichordates of doubtful affinities. *Turnicates:* Gill feeders. Mostly attached. Cephalochordates: Fishlike. Gill feeders.



AMPHIOXUS

Craniata

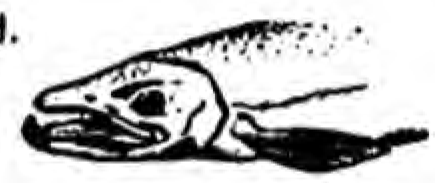
True head with definite brain and heart.

I. Jawless (*Agnatha*)

Jawless.

LAMPREY LAMPREY'S HEAD

Jawed.



SALMON'S HEAD

Mouth round and suckerlike. Not bounded by jaws. II. Jawed Mouth with upper and lower jaws.

Fishes

Cartilaginous

DOGFISH SHARK HAMMER-HEADED SHARK RAY SKATE

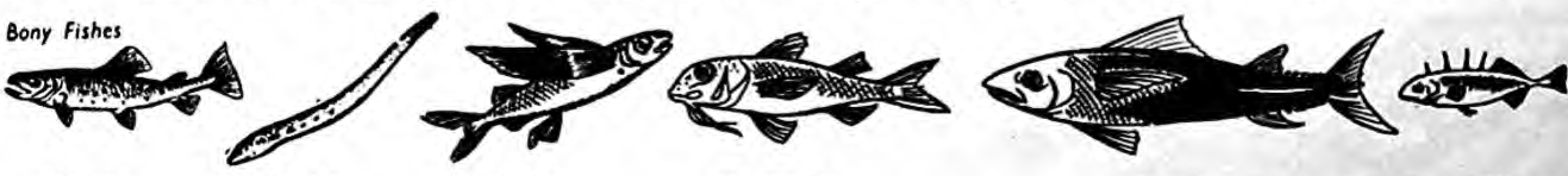
Streamlined body. Fins and tails. Scales. Gills. Heart of two chambers. Cold blooded. Egg laying vertebrates with external fertilisation,

Lung Fishes

SAWFISH COELACANTH AFRICAN MUDFISH LEPIDOSIREN MUDSKIPPER

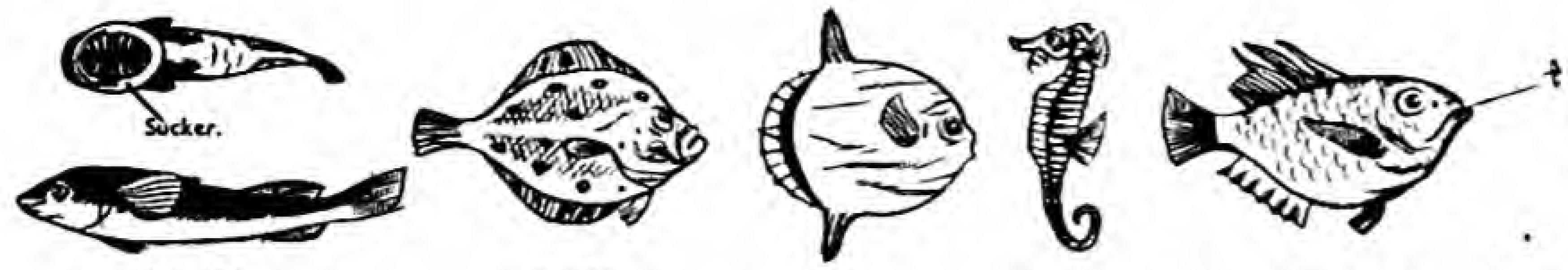
Some have internal fertilisation and eggs are laid in a shell or case. *Cartilaginous:* Cartilaginous not bony skeleton. Numerous gill slits.

Bony Fishes

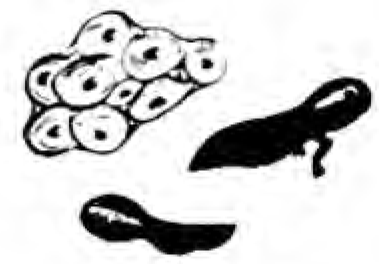


TROUT ELECTRIC EEL FLYING FISH RED MULLET TUNNEY STICKLEBACK

Lung Fishes: Lobe of body wall projects onto fin (tassel fin). One or two lungs present.



Amphibians



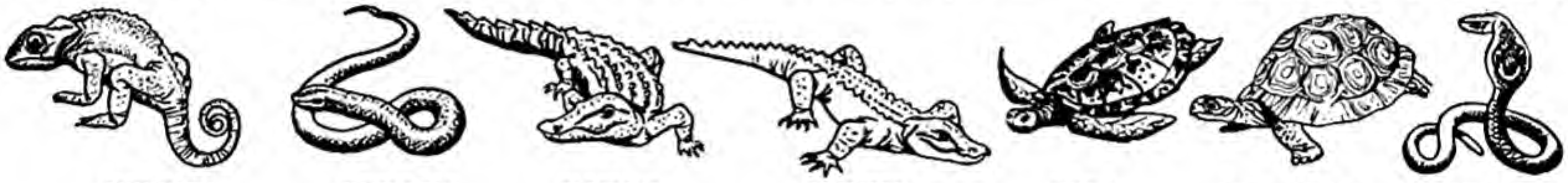
REMORA PLAICE SUNFISH SEA HORSE ARCHER FISH *Amphibians:* Fresh water LIFE CYCLE OF FROG

Bony Fishes: Skeleton ossified. Gills covered by gill plate. Scales lie within skin. breeders. Cold blooded. Moist skin. No neck.

Reptiles

FROG COMMON TOAD SURINAM TOAD NEWT SALAMANDER LIZARD

Gills in larvae. Lungs in adult. No ribs. Metamorphosis to adult. Heart incompletely divided. *Reptiles:* Cold blooded. Skin dry with horny



CHAMELEON SLOW-WORM CROCODILE ALLIGATOR TURTLE GIANT TORTOISE COBRA

scales. Lungs for respiration. Ribs. Heart almost completely divided. Internal fertilisation. (Shelled eggs laid on land.) No larval stage.

Birds (Aves)

Struthiones

Glorified reptiles. Scales only on legs. Forelimbs as wings.

OSTRICH RHEA EMU CASSOWARY KIWI

Jaws toothless—beak. Warm-blooded. *Struthiones:* Running birds that have lost the power of flight. *Colymbiformes:* Diver like birds.

PENGUIN AND SKELETON GREAT CRESTED GREBE LITTLE GREBE GREAT NORTH DIVER GANNET SHAG PELICAN

Webbed legs at rear of body. Penguins confined to Antarctic. Divers unable to walk at all. *Steganopodes:* All toes in one web.

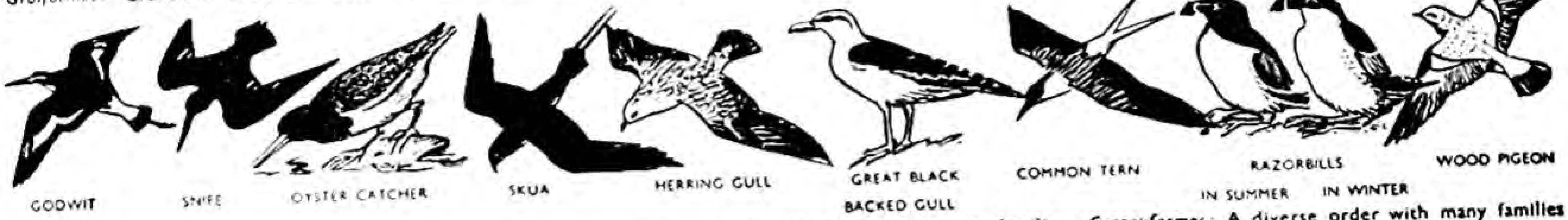
Stork-like CLAWS OF HERON HERON BITTERN STORK IBIS FLAMINGO MUTE SWAN GREY-LAG GOOSE

birds. Long legs for wading. Young long helpless and fed by regurgitation. *Anseriformes:* Goose-like birds. Water birds with webbed feet.

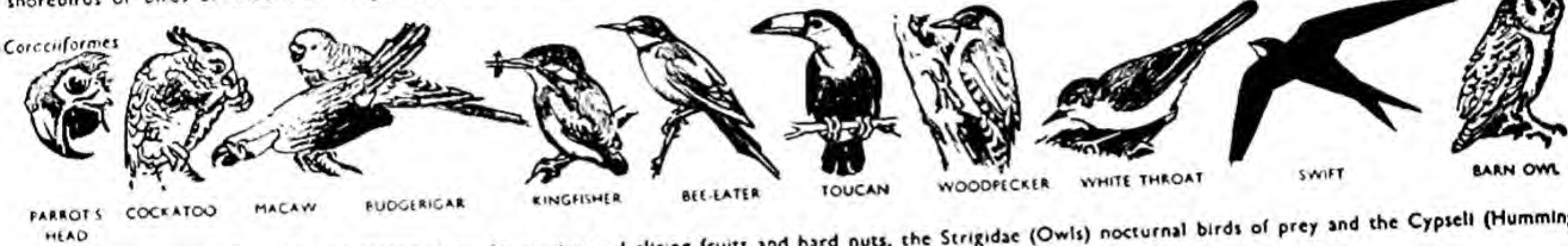
SHOVELLER DUCK EIDER DUCK BEAK AND CLAW OF EAGLE VULTURE EAGLE SPARROW HAWK BEAK AND CLAW OF PHEASANT PHEASANT HEN PEACOCK QUAIL

Acciptres: Birds of prey. Hook shaped beaks for tearing prey. Seizing claws. Keen sight. *Galliformes:* Game birds. Grain and seed eaters.

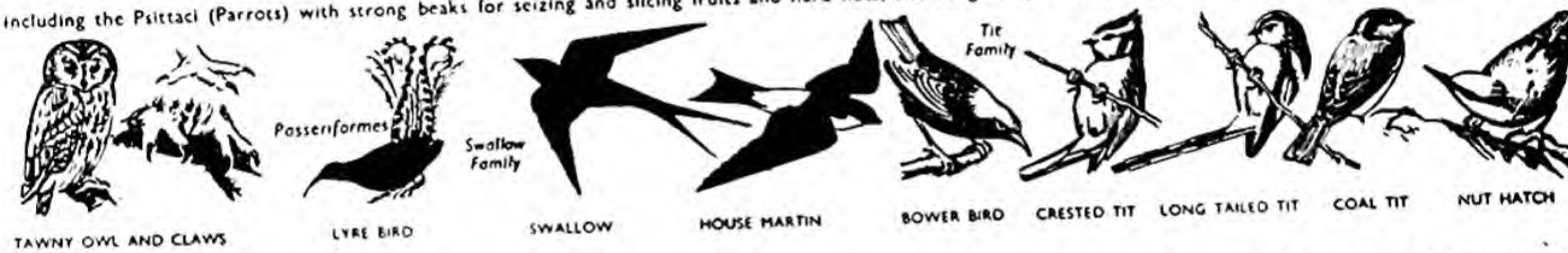
Gruiformes: Crane-like birds of marshy and wet places. Beaks rather short. *Charadriiformes*: Plover-like birds of open country, generally near water,



shorebirds or birds of moorland. Legs, necks and bills relatively long. A variable order with many families. *Coraciiformes*: A diverse order with many families



including the Psittaci (Parrots) with strong beaks for seizing and slicing fruits and hard nuts, the Strigidae (Owls) nocturnal birds of prey and the Cypseli (Humming-



birds and Swifts) continuously on the wing. *Passeriformes*: The perching birds. Foot with hind toe well developed, front toes free making grasping foot that

locks under weight of bird. These are the chief song birds, the syrinx (voice box) being very elaborate in its muscle arrangement. The young are hatched

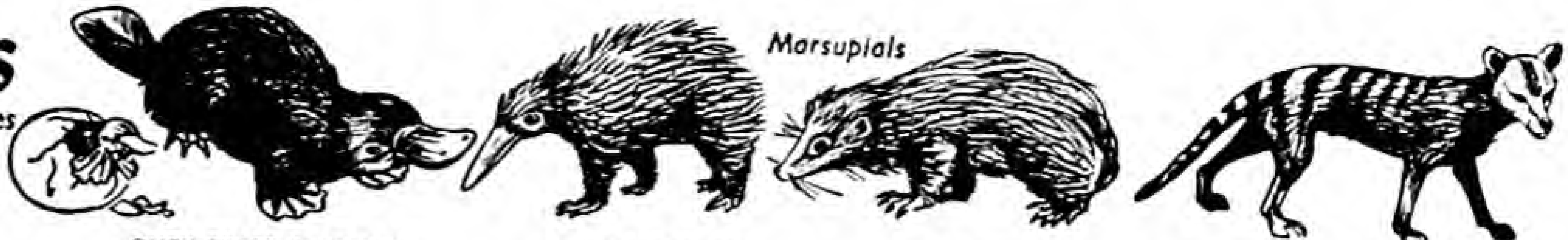
blind and remain dependent for some time. Among this order are the Finches (and Buntings), seed and nut eaters with strong to very strong bills; the Larks,

Pipits and Wagtails which mostly run when on the ground; the Rhinoceros Bird (Ox pecker) which takes flies and ticks off cattle; and the Crows and their allies.

Mammals

Monotremes

Mammals: Warm blooded,



Marsupials

DUCK BILLED PLATYPUS SPINY ANTEATER OPOSSUM TASMANIAN WOLF

milk secreting. Furry or hairy. Heart completely divided. Diaphragm and ribs. *Monotremes:* Lay eggs. Furry. No true teeth.

MARSUPIAL MOLE WOMBAT BANDICOOT KANGAROO WALLABY KOALA BEAR

Marsupials: Young born alive. Suckled in abdominal pouch by modified oil glands via nipples. Large range of types in Australia.

<u>*Placental Mammals:*</u> The higher mammals. All

Anteaters

Insectivores

ANTEATER SLOTH ARMADILLO AARDVARK SHREW

the principal modern mammals come here. Young born relatively far advanced in development. Milk glands and nipples. Great variety in adult

Rodents

MOLE HEDGEHOG RAT FLYING SQUIRREL FIELD MOUSE RABBIT RODENT'S SKULL

tooth arrangement and in limb adaptations. *Anteaters:* No front teeth. Long snouts. Insectivores : Many small sharp teeth. Long snouts.

Carnivores

HARE BEAVER JAW OF CAT CAT TIGER CHEETAH

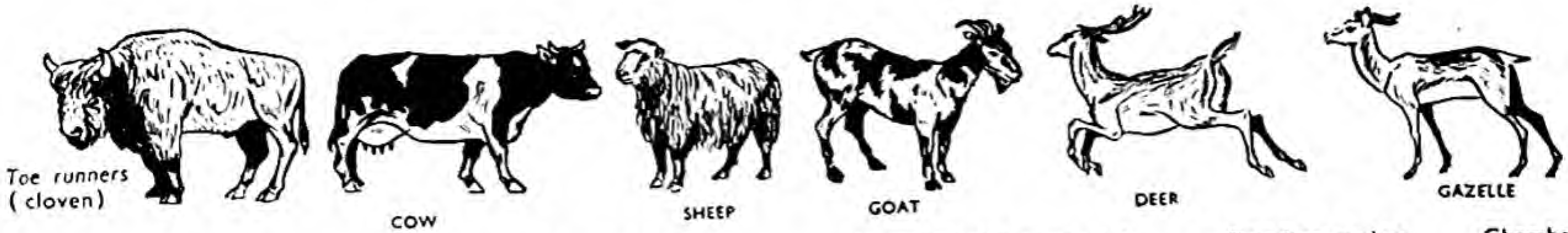
Rodents: Chisel shaped front teeth. No canine teeth. *Carnivores* (flesh eaters) : Toes with claws. Seizing incisor and flesh shearing molar

LION MONGOOSE FOX DOG WOLF

teeth. Simple stomach. Brain usually well developed. Many distinct families, among them the Cat family—lions, tigers,

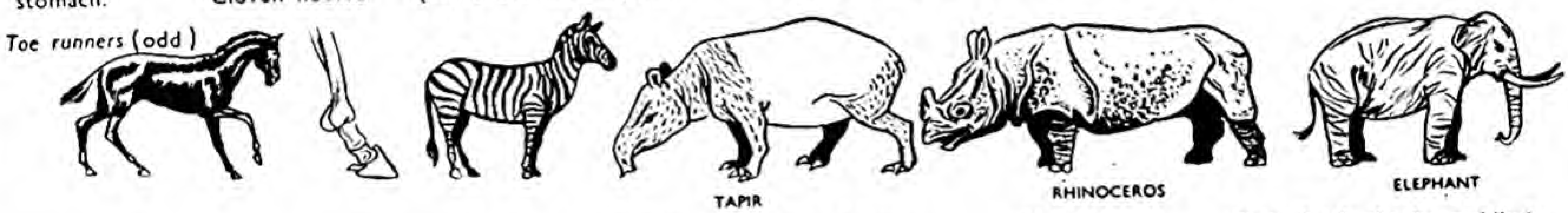
HYAENA BEAR GIANT PANDA OTTER BADGER

cheetahs, leopards, jaguars, domestic cats; and the Dog family—dogs, foxes, wolves and coyotes.



Toe runners, or ungulates: (a) Even toed, cloven hoofed. Herbivores (plant eating). Grinding molars. Chambered

stomach. Cloven hoofed (=3rd and 4th fingers) (b) Odd toed ungulates 1, 3 or 4 toes. Simple stomachs.



Herbivores. *Marine Mammals:* *Cetacea* (whales). Fish like form. No hair. Only forelimbs (as paddles).

Sirenia (sea cows) resemble Cetacea. *Pinnpedia:* Related to Carnivores. Feet as flippers. Tail very short.

Flying mammals: Forelimbs as wings. Insect and fruit eating. *Higher Mammals* (*Primates*). Five fingers and toes.

Well formed nails. First digit often opposable to rest. Large brain cases. Two teats on chest.

Vision forward enabling them to judge distances. Teeth not specialist.

MATHEMATICS AND MEASUREMENT

SOME MATHEMATICAL MEANINGS AND SIGNS

$=$ the equals sign, means "is the same as"; for example, 2 half-pennies $=$ 1 penny.

$+$ the plus sign, means "add to"; for example, $3 + 2 = 5$.

$-$ the minus sign, means "take away from"; for example, $3 - 2 = 1$.

$\times$ the multiplication sign, means "multiply by"; for example, $3 \times 4 = 12$.

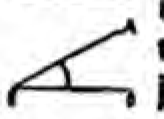
$\div$ the division sign, means "divide by": for example, $6 \div 2 = 3$.

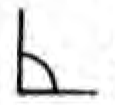
$\therefore$ means "therefore"; for example, $2 \times 2 \times 5 = 20 \quad \therefore 4 \times 5 = 20$.

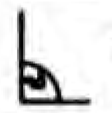
$>$ means "is greater than"; for example, $3 > 2$.

$<$ means "is less than"; for example, $2 < 3$.


represents an angle.


represents a particular angle, the angle at B made by the lines joining B to A and B to C. It is written $A\hat{B}C$ or $\llcorner ABC$. (Note that the angle is at B, and B is the middle letter in $A\hat{B}C$.)


Stands for a right angle, the angle in one quarter of a circle.


90° means an angle of 90 degrees. It is the same as a right angle.


There are 360° in a complete turn.

The denominator of a fraction is the bottom line, telling the size of the parts; for example, quarters.
The numerator of a fraction is the top line, telling the number of parts; for example, three

$$\frac{3}{4}\begin{array}{l}\leftarrow\text{numerator}\\ \leftarrow\text{denominator}\end{array}$$

DECIMALS. Scientists do not use fractions like $\frac{3}{8}$, $\frac{7}{8}$, or $\frac{11}{16}$: they use instead tenths, hundredths and thousandths, and write them in a special way, as decimals.

Examples:

$\frac{1}{10}=\cdot 1$, $\frac{6}{10}=\cdot 6$, $3\frac{6}{10}=3\cdot 6$

$\frac{1}{100}=\cdot 01$, $\frac{5}{100}=\cdot 05$, $\frac{37}{100}=\cdot 37$, $4\frac{37}{100}=4\cdot 37$

$\frac{1}{1{,}000}=\cdot 001$, $\frac{7}{1{,}000}=\cdot 007$, $\frac{23}{1{,}000}=\cdot 023$,

$\frac{521}{1{,}000}=\cdot 521$, $8\frac{521}{1{,}000}=8\cdot 521$.

SOME COMMON FRACTIONS AS DECIMALS

You will find these, and many more besides, on the micrometer (*see page 62*). This measures in the decimal system and is used by engineers who often work with ordinary fractions.

$\frac{1}{2}=\cdot 5$ $\quad$ $\frac{1}{8}=\cdot 125$
$\frac{1}{4}=\cdot 25$ $\quad$ $\frac{3}{8}=\cdot 375$
$\frac{3}{4}=\cdot 75$ $\quad$ $\frac{5}{8}=\cdot 625$
$\frac{7}{8}=\cdot 875$

THE METRIC SYSTEM. In Science it is usual to measure distances in centimetres instead of in feet and inches, and to weigh in grammes instead of in pounds and ounces. For volume, the cubic centimetre is used rather than the cubic foot.

THE METRIC SYSTEM

Length.

1,000 metres = 1 kilometre

$\frac{1}{100}$ metre = 1 centimetre

$\frac{1}{1{,}000}$ metre = 1 millimetre

$\frac{1}{1{,}000{,}000}$ metre = 1 micron

1 in. = 2·54 cm. 1 km. = ·62 mile = $\frac{5}{8}$ mile approx.

1 cm. = ·39 in. 1 mile = 1,609 metres

Weight.

1,000 grammes = 1 kilogramme

$\frac{1}{10}$ gramme = 1 decigramme

$\frac{1}{100}$ gramme = 1 centigramme

$\frac{1}{1{,}000}$ gramme = 1 milligramme

1 oz. = 28·35 gm. 1 lb. = 453·6 gm.
1 kgm. = 2·2 lb.

Volume.

1,000 cubic centimetres = 1 litre. The word "millilitre" is sometimes used instead of "cubic centimetre". 1 litre = 1·76 pints. 1 pint = 568 c.c. (or m.l). 1 cubic in. = 16·39 c.c. (or m.l).

POWERS.

$7 \times 7 = 49$ $\therefore$ seven squared is 49, or $7^2 = 49$.

$4 \times 4 \times 4 = 64$ $\therefore$ four cubed is 64, or $4^3 = 64$.

$2 \times 2 \times 2 \times 2 = 16$ $\therefore$ two to the power of four is 16, or $2^4 = 16$.

$10 \times 10 \times 10 \times 10 \times 10 \times 10 = 1{,}000{,}000$ $\therefore$ ten to the power of six is one million, or $10^6 = 1{,}000{,}000$.

The small figure, or index, shows the power to which a number is to be raised; in other words, the number of numbers to be multiplied together.

The square root of a number is a figure which when multiplied by itself gives the number in question, e.g. the square root of 4 is 2, because $2 \times 2 = 4$.

The sign for a square root is $\sqrt[2]{\ }$ or just $\sqrt{\ }$.

Examples: $\sqrt{9} = 3$; $\sqrt{25} = 5$; $\sqrt{81} = 9$; $\sqrt{100} = 10$.

$\sqrt[3]{\ }$ is the cube root. Since $3 \times 3 \times 3 = 27$, the cube root of 27 is 3 or $\sqrt[3]{27} = 3$.

Distance of the Moon from the Earth = 240,000 miles = 24×10^4 miles = $2\cdot 4 \times 10^5$ miles.

Distance of the Sun from the Earth = 93,000,000 miles = 93×10^6 miles or $9\cdot 3 \times 10^7$ miles.

1 light year = the distance travelled by a wave of light in one year = 6,000,000,000,000 miles = 6×10^{12} miles.

The coefficient of linear expansion of the metal platinum is ·000009 =

$$9 \times \frac{1}{1{,}000{,}000} = 9 \times \frac{1}{10^6} = 9 \times 10^{-6}$$

(read as "nine times ten to the power of minus six").

The number π (pronounced as "pie"). When the distance around the edge of a circle (its circumference) is divided by the greatest distance across the circle (its diameter), the result is always the same, no matter how large or small the circle. It is 3·14 or $3\frac{1}{7}$ ($\frac{22}{7}$). As it never varies, it is called a "constant", and given the name π.

PHYSICS FORMULAE. To save time, most problems in Physics are worked out by means of a formula, in which letters stand for the figures which will later replace them. Here are a few which occur in this book:

$$v^2 = u^2 + 2aS$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$C = \frac{5(F - 32)}{9}$$

We often need to change a formula to make it more convenient to work out the result, yet it must still remain true. One mathematical rule allows us to change a letter (or figure) from one side of the equation to the other, so long as we change its sign at the same time. For example:

$$a + b = c - d$$
$$\therefore a = c - d - b$$
or $$a + b + d = c$$
or $$a + b - c + d = 0$$

Another mathematical rule allows us to "cross-multiply"; that is, change a denominator on one side of the equals sign into the numerator on the other, and vice versa. For example:

$$\frac{w}{x} = \frac{y}{z}$$
$$\therefore w = \frac{xy}{z}$$
or $$\frac{w}{y} = \frac{x}{z}$$
or $$wz = xy.$$

Here is an actual physics formula being changed, using both these devices:

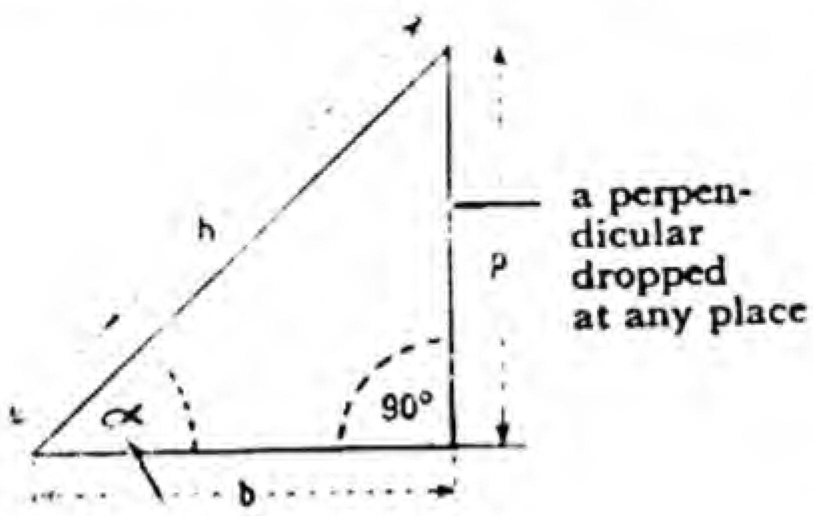
$$C=\frac{5(F-32)}{9}$$

$9C = 5(F-32)$ Cross-multiplying

$\frac{9C}{5} = F - 32$ Cross-multiplying

$\frac{9C}{5} + 32 = F$ Changing the sign on changing sides.

THE TRIGONOMETRICAL RATIOS



the angle (alpha)

b = length of the base

p = length of the perpendicular

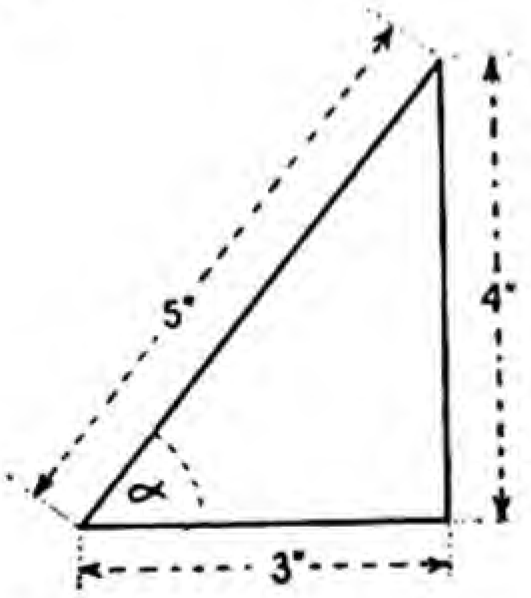
h = length of the hypotenuse (longest side of a right-angled triangle).

The sine of the angle α, written Sin. $\alpha = \frac{p}{h}$

The cosine of the angle α, written Cos. $\alpha = \frac{b}{h}$

The tangent of the angle α, written Tan. $\alpha = \frac{p}{b}$

Example:

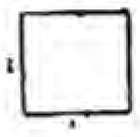
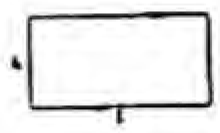
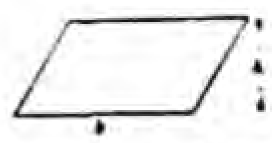
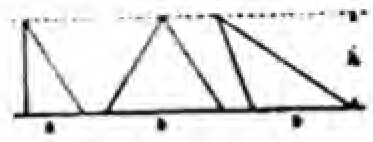
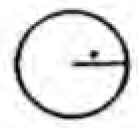


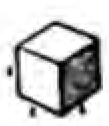
$$\text{Sin. } \alpha = \frac{p}{h} = \frac{4}{5} = \cdot 8$$

$$\text{Cos. } \alpha = \frac{b}{h} = \frac{3}{5} = \cdot 6$$

$$\text{Tan. } \alpha = \frac{p}{b} = \frac{4}{3} = 1{\cdot}33$$

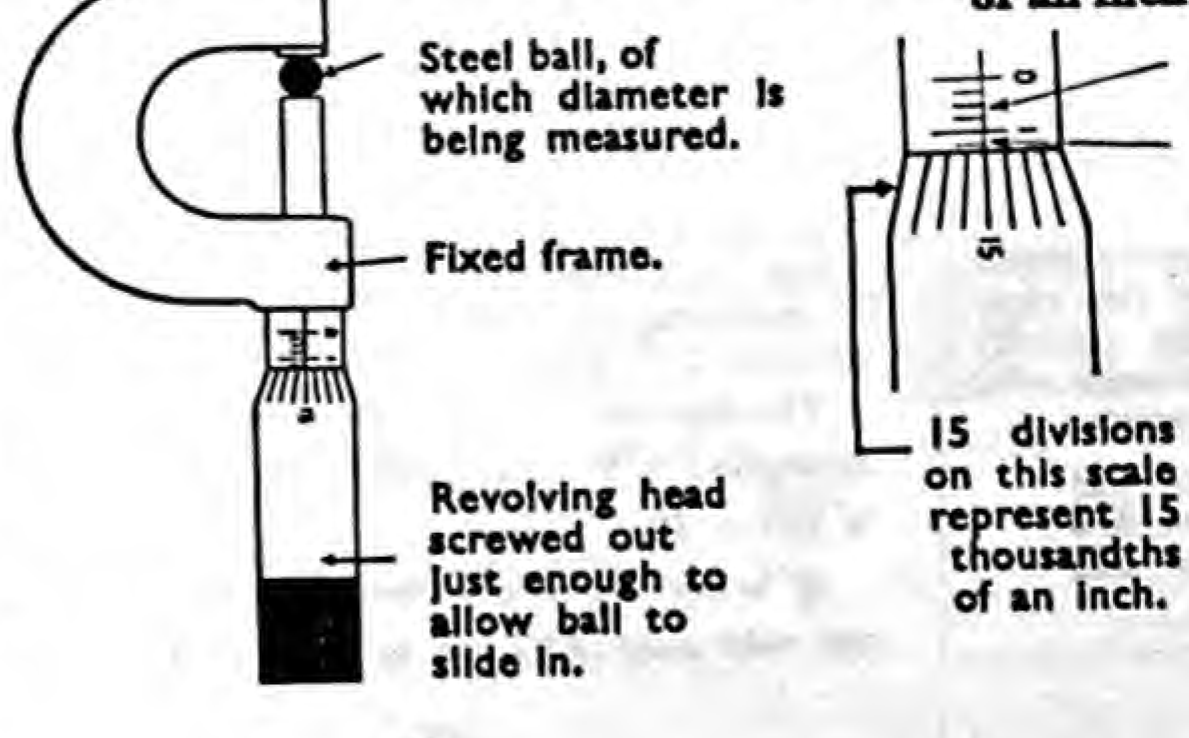
The sines, cosines and tangents for all angles are to be found ready worked out in Mathematical Tables.

AREAS			
Figure	*Illustration*	*Method*	*Formula*
Square		Multiply the length of the side by itself	$A = l^2$
Rectangle		Multiply the length of the side by the height	$A = l \times h$
Parallelogram		Multiply the length of the base by the vertical height	$A = b \times h$
Triangle		Multiply the length of the base by half the vertical height	$A = \frac{b \times h}{2}$
Circle		Multiply the radius by itself and then multiply by π	$A = \pi r^2$

VOLUMES			
Figure	*Illustration*	*Method*	*Formula*
Cube		Multiply the length of the side by itself and multiply the result by length of the side	$V = l^3$
Sphere		Multiply the radius by itself and multiply the result by the radius again. Now multiply by π, then by 4 and finally divide by 3	$V = \frac{4}{3}\pi r^3$

Length	*Area*	*Volume*
12 in. = 1 foot.	144 sq. in. (12^2) = 1 sq. ft.	1,728 cub. in. (12^3) = 1 cub ft.
3 ft. = 1 yard	9 sq. ft. (3^2) = 1 sq. yd.	27 cub. ft. (3^3) = 1 cub. yd.
		1 cub. ft. = 6·23 gallons
100 cm. = 1 metre	10,000 sq. cm. (100^2) = 1 sq. metre	1,000,000, c.c. (100^3) = 1 cub. metre
		1,000 c.c. = 1 litre

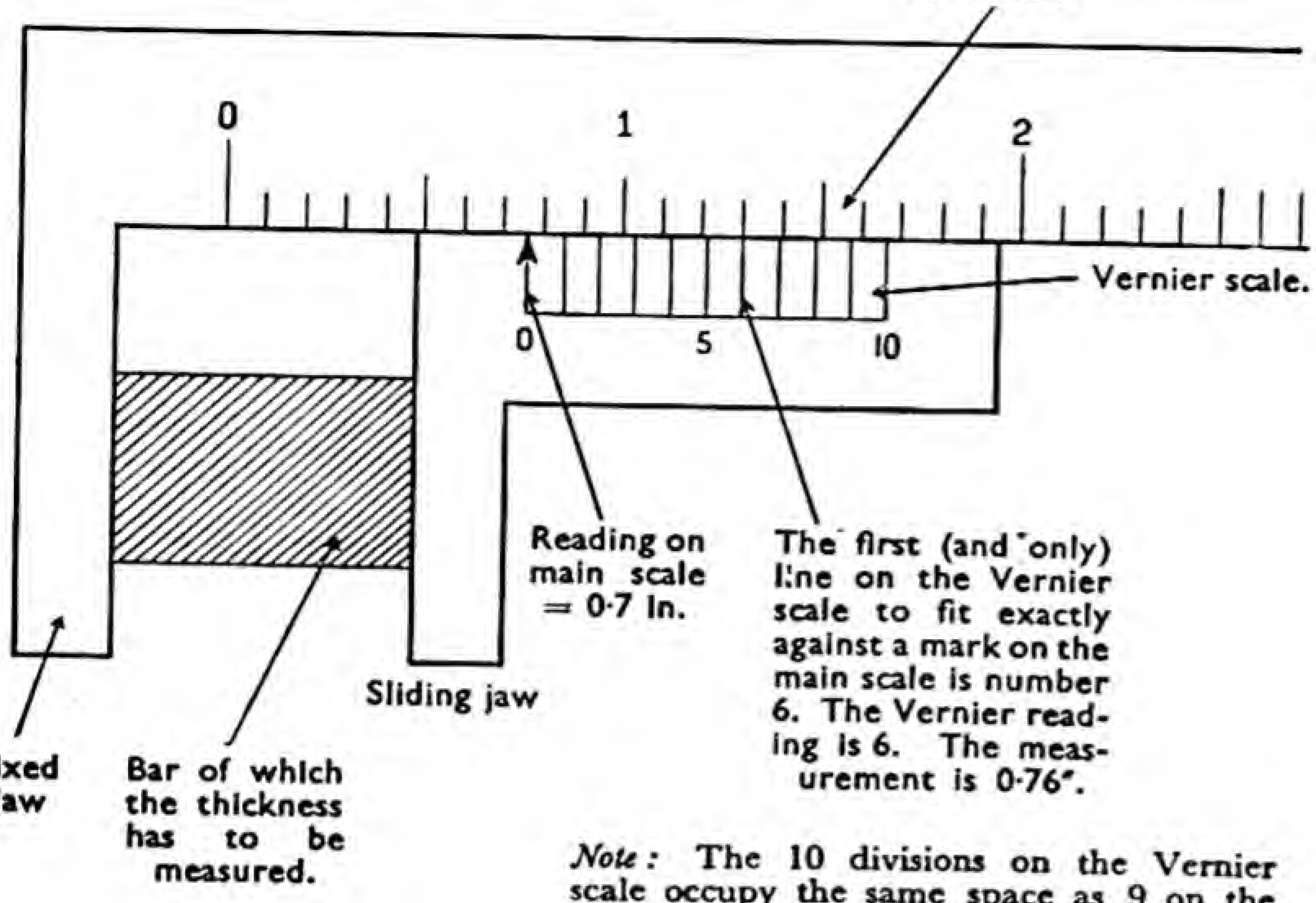
The micrometer, which measures to one thousandth of an inch



∴ Diameter of ball

= ·1 in.	or	100 thou.
·025 in.	or	25 thou.
·015 in.	or	15 thou.
·140 in.	or	140 thou.

Using a Vernier Scale



Note: The 10 divisions on the Vernier scale occupy the same space as 9 on the main scale.

Logarithms

10 squared or $10^2 = 100$. The logarithm of 100 is 2.

10 cubed or $10^3 = 1{,}000$. The logarithm of 1,000 is 3.

10 to the power of 8 or $10^8 = 100{,}000{,}000$. The logarithm of 100,000,000 is 8.

The logarithm of any number is the power to which 10 must be raised to give the number.

Logarithm Tables.

The logarithms of all numbers have been worked out and set out in Tables. For ordinary work, "Four-figure logarithms" are used—that is, logarithms calculated to four places of decimals.

Examples: In the logarithm tables, against 16 appears the figures ·2041.

The logarithm of	1·6	= 0·2041.
" " "	16	= 1·2041.
" " "	160	= 2·2041.
" " "	1,600	= 3·2041.

Note that the decimal portion of the logarithm remains the same—it is determined by the figure 16. The whole number of the logarithm is obtained by counting the figures on the left-hand side of the decimal point in the number of which the logarithm is required, and reducing by one, e.g. 160 or 160·0 has 3 figures to the left of the decimal point so the logarithm is 2 point something—2·2041 in fact.

Note: It is possible to write down the logarithms of numbers less than one. Readers who are interested in these are advised to consult a mathematics text-book, where the theory and method will be fully explained.

Multiplication using logarithms.

Rule: Write down the logarithms of all the numbers, add them together and find, in the tables, the number which has a logarithm the same as the total.

Example: 1,600 × 450 × 9·1.

Logarithm of 1,600	= log.1600	=	3·2041
Logarithm of 450	= log. 450	=	2·6532
Logarithm of 9·1	= log. 9·1	=	·9590
			6·8163

Now consider the decimal portion of the total, ·8163. From the Tables, the number which has a logarithm of ·8163 = 6551.

Now consider the whole number portion of the total, i.e. 6. Since we take one away from the number of figures before the decimal to obtain the logarithm, we reverse the process and add one to get the answer from the logarithm.

∴ there are 6 + 1 = 7 figures before the decimal point.

∴ the answer is 6551000·0 or 6,551,000

∴ 1,600 × 450 × 9·1 = 6,551,000.

Consider another example:

2·7 × 63 × 481.

Log. 2·7	= 0·4314
Log. 63	= 1·7993
Log. 481	= 2·6821
	4·9128

The number of which ·9128 is the logarithm is 8·181.

The number of which 4·9128 is the logarithm is 81810.

∴ 2·7 × 63 × 481 = 81,810.

Division by means of logarithms.

The method is identical except that the logarithm of the divisor is subtracted from the logarithm of the number to be divided.

Example: 563 ÷ 3·8.

Log. 563	= 2·7505
Log. 3·8	= 0·5798
Difference	= 2·1707

The number of which ·1707 is the logarithm is 1·418.

The number of which 2·1707 is the logarithm is 148·1.

∴ 563 ÷ 3·8 = 148·1.

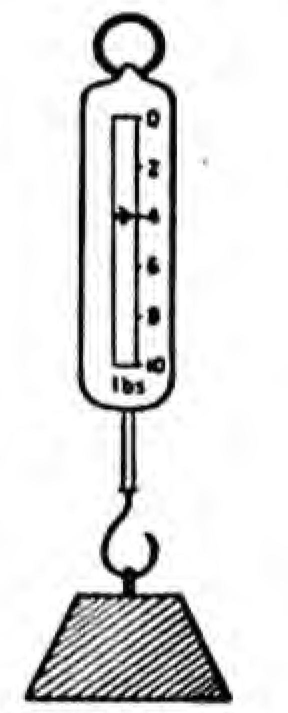
WEIGHT. All objects fall to the ground: they are attracted by the Earth (the force of gravity). The pull of the Earth upon an object is its "*weight*". The attraction of the Earth changes according to the distance from the centre of the Earth, so the "weight" of the same object can vary. The "weight" of an object is measured by the attraction of the Earth as shown by pulling out the spring in a spring balance.

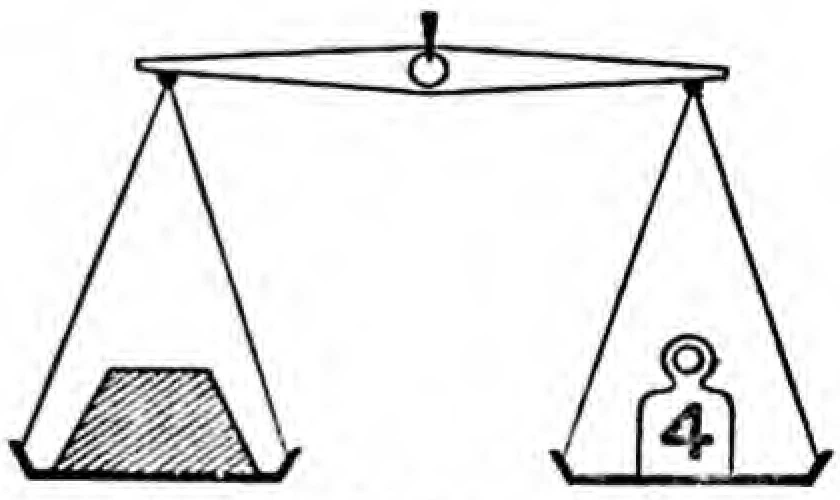
MASS. This is the "amount of substance" in an object—it is a fixed amount and does not vary with the pull of the Earth. The mass is found by comparing, on a pair of scales, with other objects of known mass, usually "weights", i.e. pieces of metal with their masses stamped upon them.

Weight and Mass are measured in the same units, e.g. pounds or grammes. Under ordinary circumstances the mass and the weight are the same. We might however take a 7 lb. weight a few thousand miles above the Earth to where the attraction of gravity is only $\frac{1}{7}$ as strong as on the Earth. Here the "weight" is 1 lb.; but there is still just as much iron in the weight, so its mass remains at 7 lb.

Weight

The weight of this piece of metal is 4 lb. because the pull of the Earth upon it extends the spring to the 4-lb. mark (i.e. with a force of 4 lb.).





Mass

The mass of the metal is also 4 lb. because it exactly balances a piece of brass known to have a mass of 4 lb.; i.e. the 4-lb. "weight" from a set of weights.

DENSITY

Iron is "heavier than water", yet a bucket of water weighs more than an iron nail. For a fair comparison, we must take equal volumes.

The Density of a Substance is the mass of unit volume.

Example 1: The density of aluminium is 2·7 gm. per c.c.

Example 2: The density of water is 62·4 lb. per cub. ft.

A TABLE OF DENSITIES

	g. per. c.c.	lb. per cub. ft.
Aluminium	2·7	169
Chromium	7·1	444
Copper	8·93	558
Gold	19·32	1,207
Iron	7·87	492
Lead	11·37	710
Magnesium	1·74	109
Mercury	13·56	847
Silver	10·5	656
Zinc	7·1	444
Brass*	8·5	531
Bronze*	8·8	550
Duralumin*	2·8	175
Steel	7·8	487
Balsa Wood*	·15	9·4
Bamboo*	·4	25
Cork*	·25	16
Ebony*	1·2	75
Oak*	·8	50
Glass (ordinary)*	2·5	156
Ice*	·92	57·4
Sand*	2·6	162
Methylated Spirit*	·83	51·9
Milk*	1·03	64·3
Paraffin*	·8	50
Petrol*	·7	43·7
Seawater*	1·03	64·3
Water (fresh)	1	62·43

* Average value.

The Density Formula:

Mass = Volume × Density

$$M = V \times D$$

Example 1: Find the weight of 10 cub. ft. of water.

$M = V \times D = 10$ cub. ft. × 62·4 lb. per cub. ft. = 624 lb.

Example 2: Calculate the weight of 20 c.c. of aluminium.

$M = V \times D = 20$ c.c. × 2·7 gm. per c.c. = 54 gm.

Example 3: A block of wood 3 ft. long, 2 ft. wide and 1 ft. high weighs 300 lb. What is the density of the wood?

$V = 3$ ft. × 2 ft. × 1 ft. = 6 cub. ft.

$M = V \times D \therefore$ 300 lb. = 6 cub. ft. × D

$$\therefore D = \frac{300 \text{ lb.}}{6 \text{ cub. ft.}} = 50 \text{ lb. per cub. ft.}$$

Example 4: A ring made of pure gold weighs 38·6 gm. Find the volume of the gold.

$M = V \times D \therefore$ 38·6 gm. = V × 19·3 gm. per c.c.

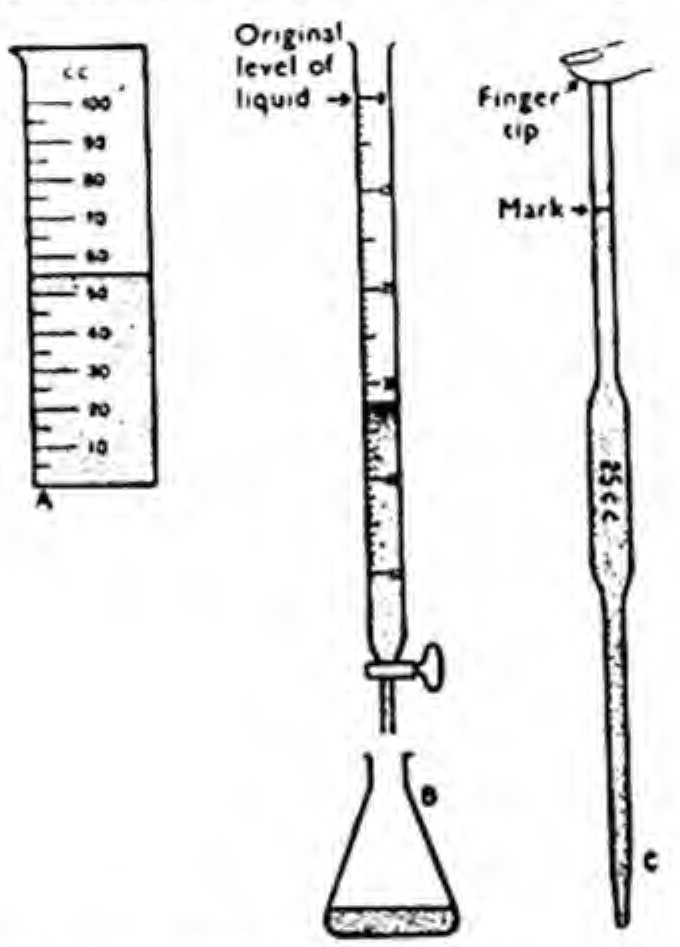
$$\therefore V = \frac{38{\cdot}6 \text{ gm.}}{19{\cdot}3 \text{ gm. per c.c.}} = 2 \text{ c.c.}$$

SPECIFIC GRAVITY. This is the mass of a substance divided by the mass of an equal volume of water; in other words the number of times a substance is heavier than water. It is a *number*, such as 13·6, and has no units like density, e.g. 13·6 gm. per c.c.

SPECIFIC GRAVITIES

Substance	*Density* lb. per c. ft.	*Density* gm. per c.c.	*Specific Gravity*
Water	62·4	1	1
Aluminium	169	2·7	2·7
Mercury	847	13·56	13·56
Gold	1,207	19·32	19·32
Cool air	·07	·0012	·0012

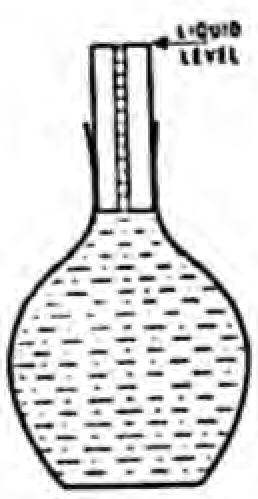
Measuring instruments for liquids



(A) A measuring cylinder containing 55 c.c. of liquid.

(B) A burette from which 32 c.c. of liquid have been run out.

(C) The pipette is about to deliver exactly 25 c.c. of liquid. It is filled by suction from the mouth; the liquid will run out when the finger is removed.



A specific-gravity bottle used to find specific gravity of a liquid. The special glass stopper, with a fine tube through it, ensures that the bottle contains exactly the same volume of liquid in each experiment.

An experimental result:

Mass of bottle empty	= 11·0 gm.
Mass of bottle filled with water	= 21·0 gm.
∴ Mass of water	= 10·0 gm.
Mass of bottle filled with glycerine	= 23·5 gm.
Mass of bottle empty	= 11·0 gm.
Mass of glycerine	= 12·5 gm.

$$\text{S.G. of glycerine} = \frac{12{\cdot}5 \text{ gm.}}{10 \text{ gm.}} = 1{\cdot}25$$

Examples on Specific Gravity.

Example 1: A 5-gallon drum holds 45 lb. of oil or 50 lb. of water. Find the specific gravity of the oil.

$$\text{S.G. of oil} = \frac{\text{mass of oil}}{\text{mass of water}} = \frac{45 \text{ lb.}}{50 \text{ lb.}} = \frac{9}{10} = {\cdot}9.$$

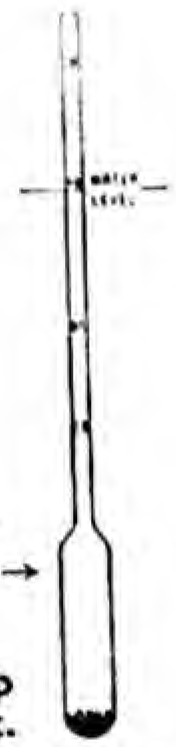
Example 2: A steel girder weighing 400 lb. is to be replaced with one of aluminium alloy. S.G. of this steel = 8; s.g. of alloy = 3. What will the new girder weigh?

$$\frac{\text{Mass of aluminium}}{\text{Mass of steel}} = \frac{\text{S.G. of aluminium}}{\text{S.G. of steel}} = \frac{3}{8}$$

$$\text{Mass of new girder} = \frac{3}{8} \times \text{weight of old}$$

$$= \frac{3}{8} \times 400 \text{ lb.} = 3 \times 50 \text{ lb.} = 150 \text{ lb.}$$

A hydrometer

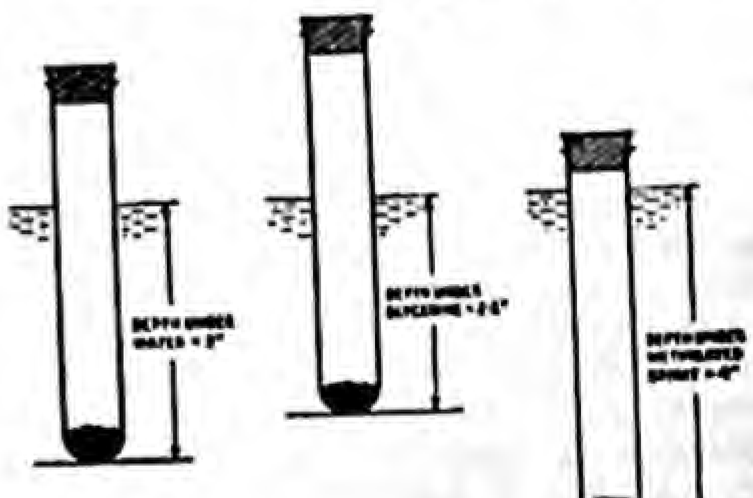


Hollow cylinder to make it float. →

Lead shot to keep it upright.

THE HYDROMETER. This is an instrument which floats in the liquid of which the specific gravity is to be found. It is rapid in use, and no weighings are required. It is used to test the acid in car batteries (a run-down battery has acid of low specific gravity) and to test milk (the addition of water or the removal of cream both alter the specific gravity).

A home-made hydrometer



$$\text{S.G. of glycerine} = \frac{\text{depth under water}}{\text{depth under glycerine}} = \frac{3 \text{ in.}}{2{\cdot}5 \text{ in.}} = \frac{6 \text{ in.}}{5 \text{ in.}} = 1{\cdot}2.$$

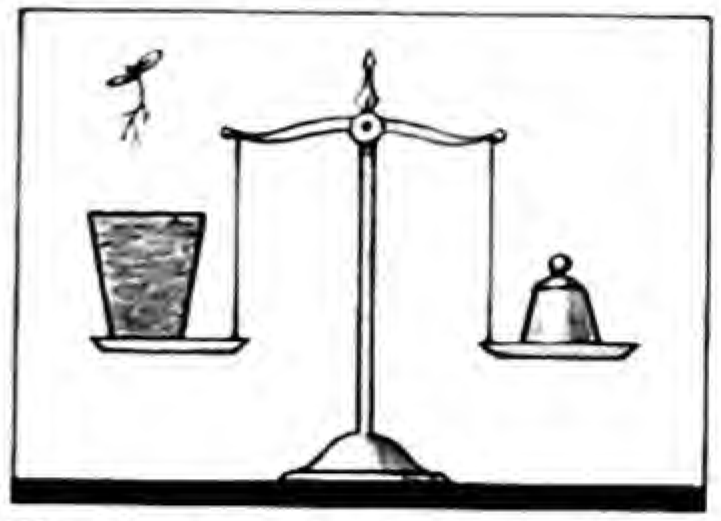
S.G. of methylated spirit

$$= \frac{\text{depth under water}}{\text{depth under methylated spirit}} = \frac{3 \text{ in.}}{4 \text{ in.}} = {\cdot}75.$$

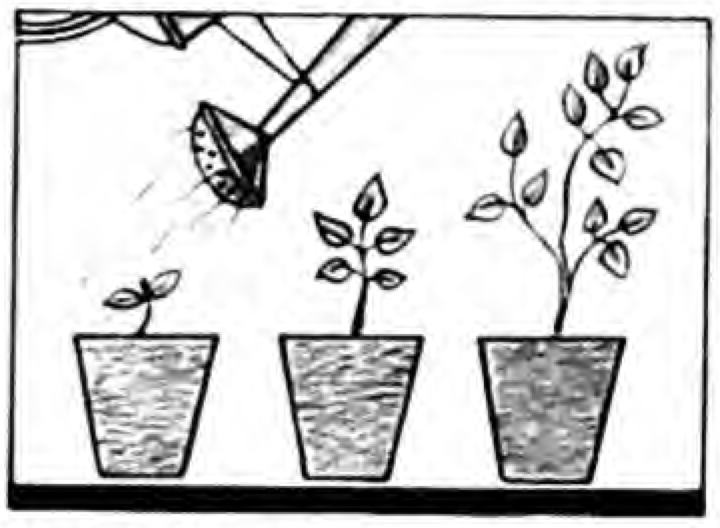
THE BIOLOGIST AT WORK

Biology is the study of living things, whether plants, animals or the microscopic bacteria. Biologists in recent years have extended this range to include the viruses. These are so small that they are invisible under ordinary microscopes. They lie near the boundary between the world of living things and the world of chemists' crystals.

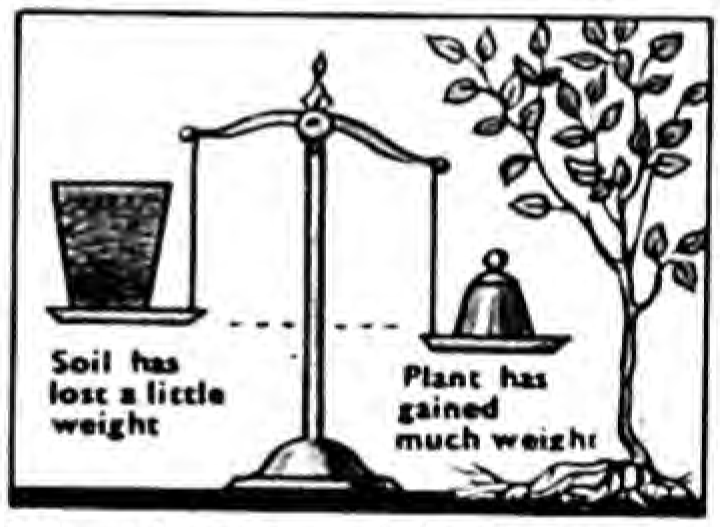
During the 18th century some biologists were using the microscope to help them discover what plants and animals were made of and the purpose of their various parts. Others sought better ways of naming and classifying the ever increasing number of known plants and animals. Simple, but sound experiments were also being done to find out why living things decay after death.



To carry out an experiment similar to van Helmont's, first weigh the plant and soil.



Keep the plant watered and wait until it has grown very much bigger.



The plant is weighed after all moisture has dried out. It still weighs much more.

Experimenting with Plants

At one time it was thought that plants grew by taking all the materials for their growth from the soil through their roots.

About 1625 van Helmont, born in Brussels in 1577, planted a willow in a weighed amount of dried earth, and grew it by giving it only water. At the end of five years he found it was 164 pounds heavier. But the soil when re-weighed was found to weigh only two ounces less than at first. Obviously the plant was chiefly gaining weight from something other than the soil.

Types of Leaf

LINEAR daffodil

OVATE privet

ELLIPTIC plantain

SAGITATE arrowroot

CORDATE spinach

PINNATIFID dandelion

PELTATE garden nasturtium

LANCEOLATE orchis

PINNATE (cordate leaflets) rose

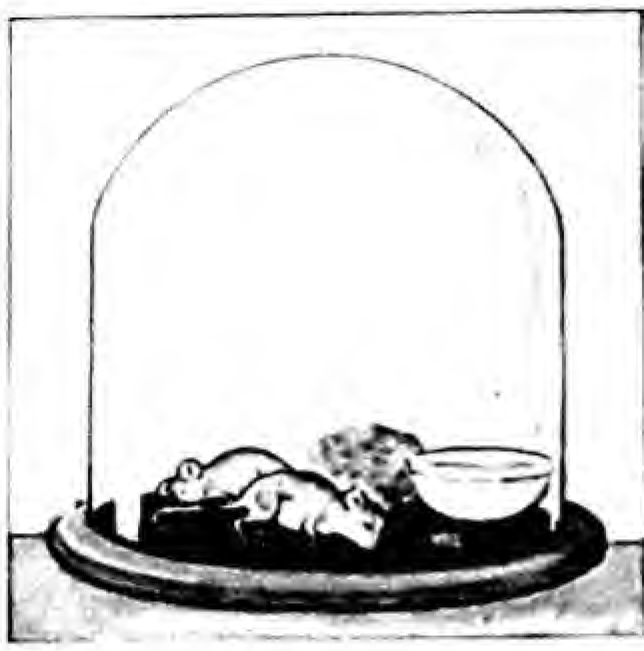
TERNATE strawberry

DIGITATE chestnut

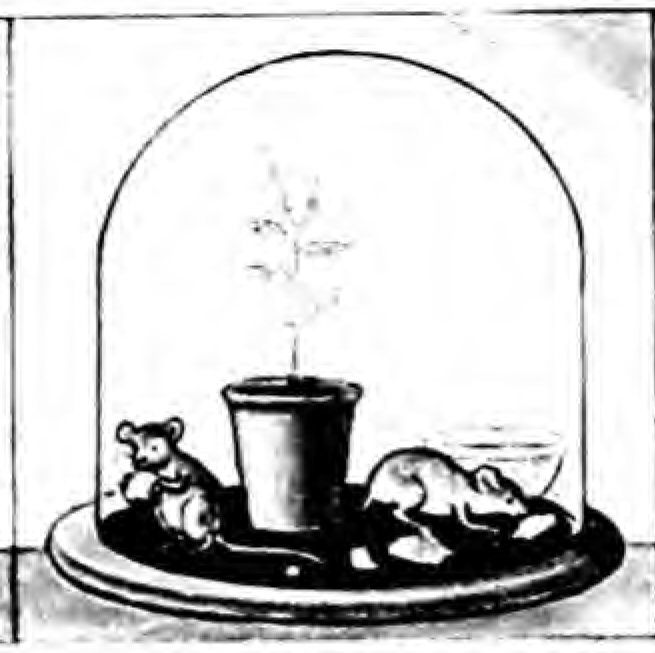
BIPINNATE angelica

PALMATE fan palm

PINNATE (linear leaflets) feather palm



Mice kept in an airtight jar soon die because only bad air is left in it.



If a growing plant is placed in the jar they live quite happily.

This is because the plant is producing oxygen in place of the bad air.

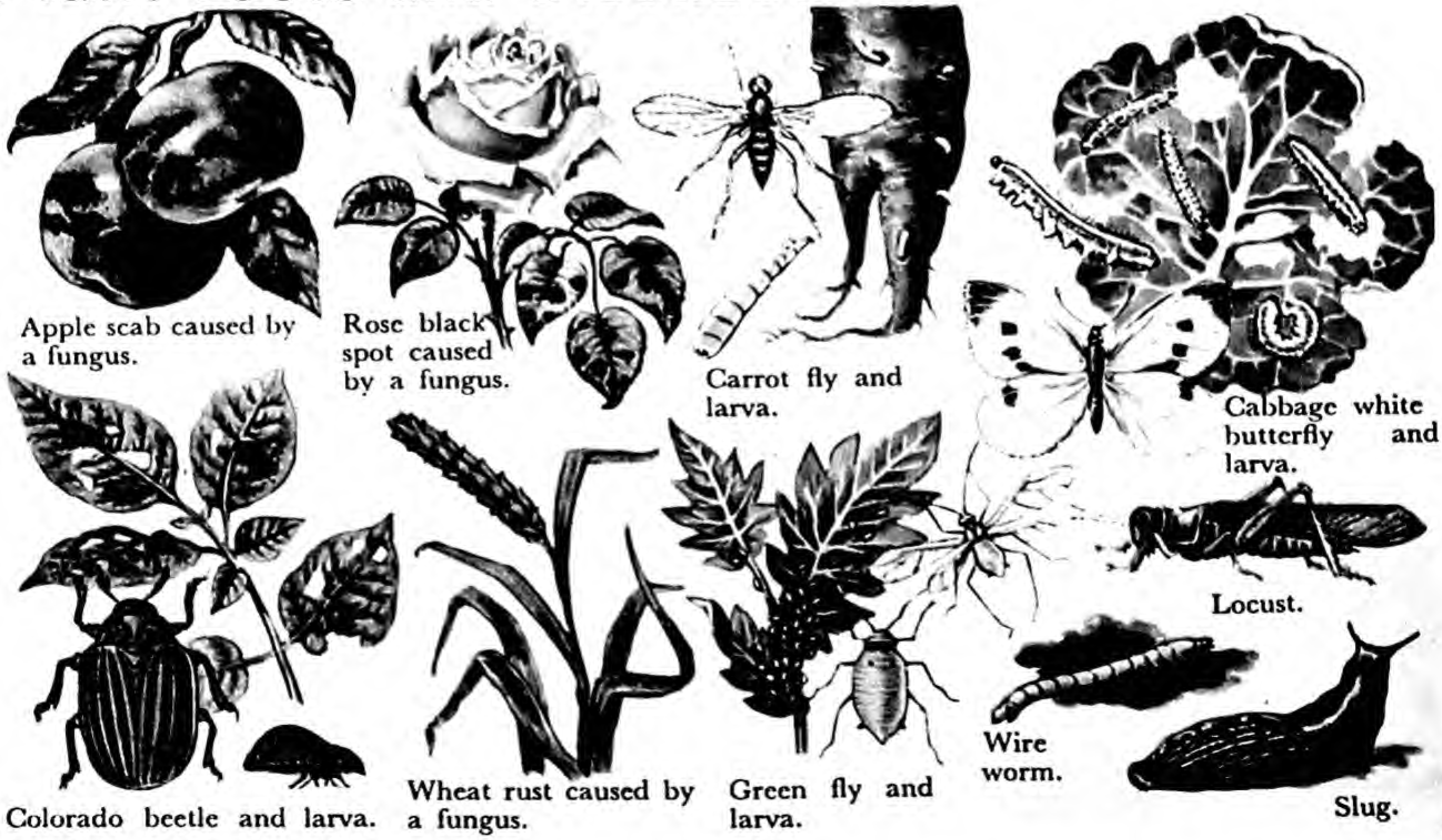
Without sunlight the plant stops producing oxygen and the mice die.

Mistakenly van Helmont thought it was from the water he had given it. But in 1727 Stephen Hales, an English clergyman, showed that the weight of water taken up by the roots of a plant was in fact the same as the amount of water lost from its leaves by evaporation.

Only when the chemists had advanced to the stage where analysis of the gases of the air was possible could the biologists go much further.

Mice kept in an airtight glass jar were known to die after a time—even though given food and water. The bad air left in the jar would not keep alight a flame—it was *incombustible*. But Joseph Priestley (1733-1804), another English minister of religion, who "discovered" oxygen at

Plant Pests and Diseases



Apple scab caused by a fungus.

Rose black spot caused by a fungus.

Carrot fly and larva.

Cabbage white butterfly and larva.

Locust.

Colorado beetle and larva.

Wheat rust caused by a fungus.

Green fly and larva.

Wire worm.

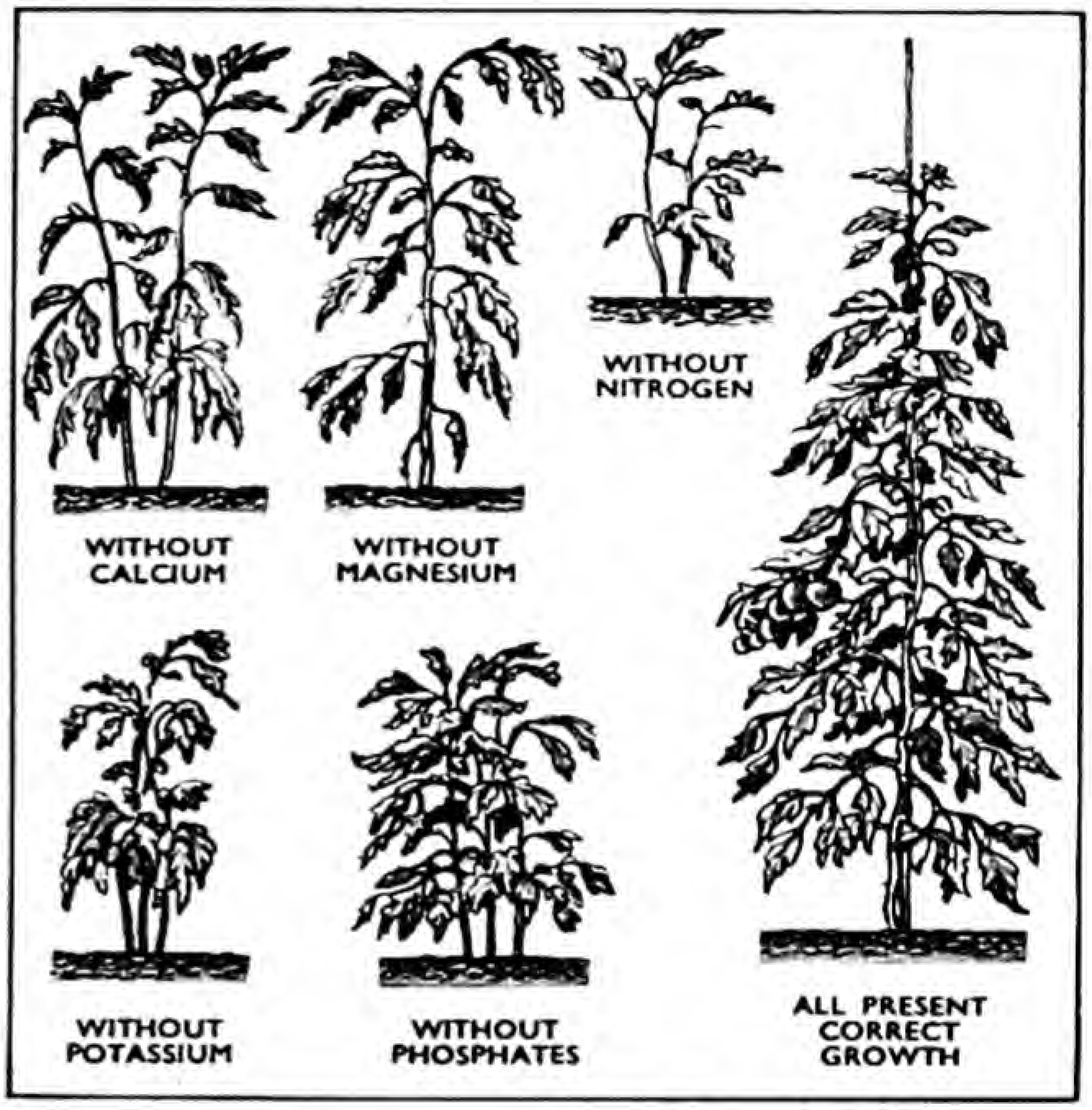
Slug.

about the same time as several other European chemists, showed that sprigs of mint would produce oxygen and would purify the *incombustible* air. For if placed in the glass jar containing the mice, these would then go on living quite happily. This fact was argued about at first because of the failure to recognise that this only happened if the mint was exposed to sunlight *(see page* 36*)*.

By 1804 de Saussure, in Geneva, carried out a more up-to-date version of van Helmont's experiment. As well as following the plant's gain and the soil's loss in weight, he was able, in view of the improvements in chemistry, to measure also the changing composition of the air surrounding the growing plant. This showed that, in sunlight, a green plant takes from the air the *incombustible* portion, known as carbon dioxide, keeps the carbon portion, which combined with water produces *carbohydrates*—such as sugar, starch and paper—which gives it its gain in weight. It returns to the air the same amount of oxygen as it took of carbon dioxide. It is this oxygen the plants produce that replaces the oxygen used up in breathing by all animals.

Biologists experimented further to find out what it was that plants needed to get in small amounts from the soil by means of their roots. They chemically analysed soil, and also the ashes of plants in their search for the answer. They found a number of chemical elements in both soil and plants. Several plants of the same kind were then grown in water culture, that is in watery solutions without any soil. Some plants were in pure distilled water. Others in dilute chemical solutions. These solutions were in the form of a series, so arranged that from the solution in each flask one of the salts under test was left out, a different one in each case. Only one flask contained a complete solution of all the necessary salts and only in this solution would the plants grow and flourish. In the others, growth was either imperfect, or the plants quickly died.

In recent times physicists have, in the form of radioactive isotopes of elements, given biologists their latest method by



Tomato plants grown in pure sand and watered with solutions from which various salts are missing. The improvement in growth when all the salts are present can be seen on the right.

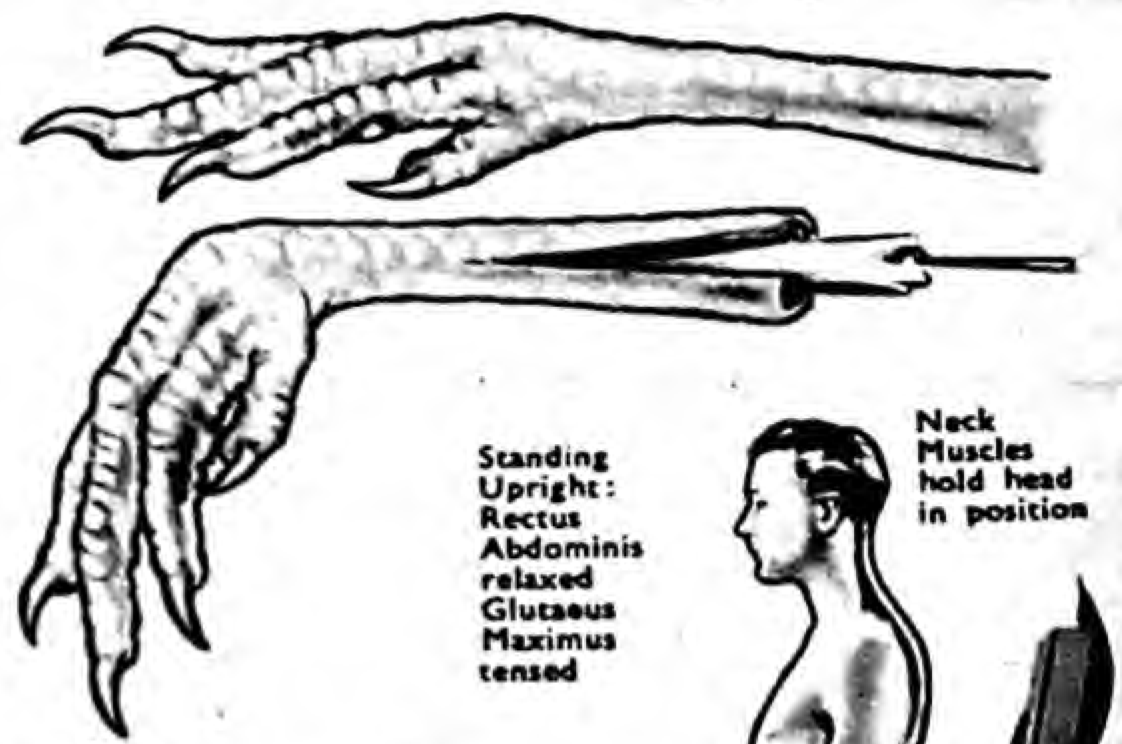
which to follow how foodstuffs move into the plant from soil and air, and to watch how they move about in the living plant.

Radioactive carbon dioxide is made from radioactive carbon. Some is then introduced into the air in an illuminated bell jar where a plant is growing. When the plant has lived in this atmosphere for some time it is taken out and tested with a geiger counter (*see page* 78). The results show that radioactive carbon is now in the plant. It appears first in the leaf cells and only later in the stem and in storage tissues such as the root or the seeds. So checking what had previously only been deductions from measurements.

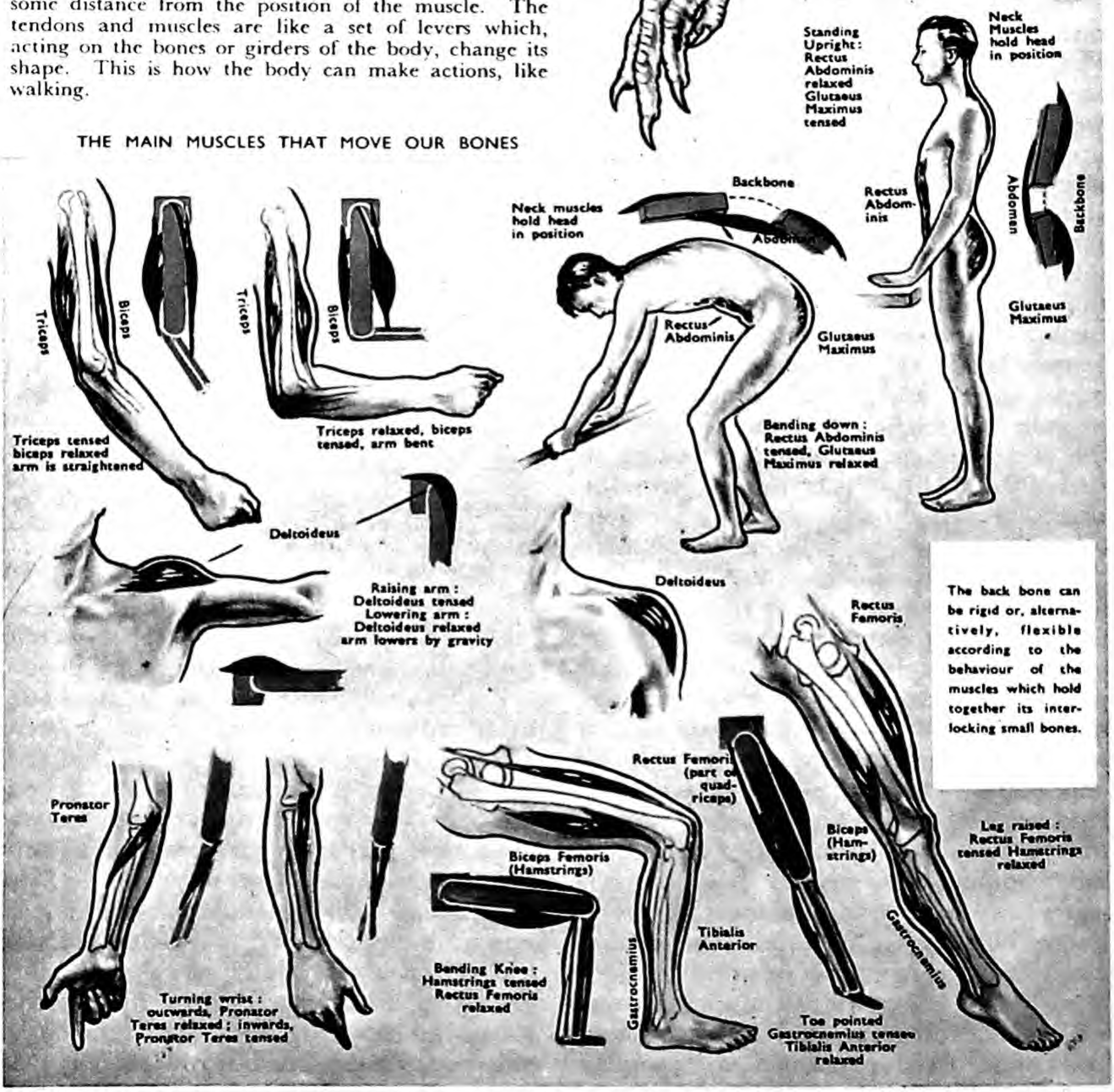
THE BIOLOGIST AND ANIMALS

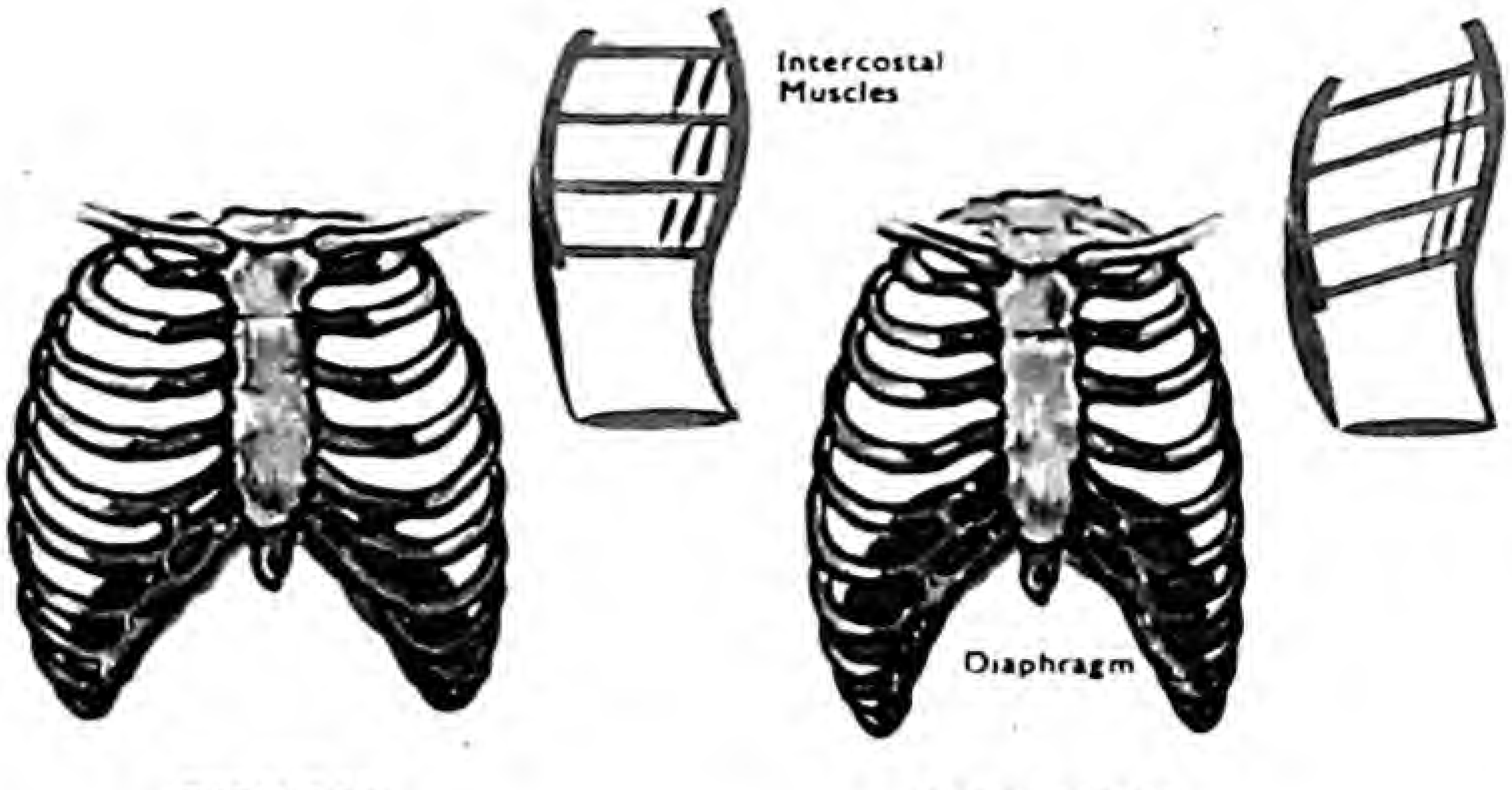
The construction of the body of a rabbit or even of a human being could be mapped out by the early anatomists even as long ago as A.D. 150. Because it could be revealed by dissection, it was discovered that vertebrate, or back-boned animals have a system of bones giving them strength and support like the girders in a building. These bones are joined together and are enveloped by the meat or flesh of the animal. This meat consists of numerous packets of elastic material, the muscles. They are attached at each end to bone, often through a rope-like tendon if the attachment is at some distance from the position of the muscle. The tendons and muscles are like a set of levers which, acting on the bones or girders of the body, change its shape. This is how the body can make actions, like walking.

The claws of a chicken's foot will move when you pull the tendons. In life, muscles higher up the leg do the pulling.



THE MAIN MUSCLES THAT MOVE OUR BONES





EXPANDED CHEST

CONTRACTED CHEST

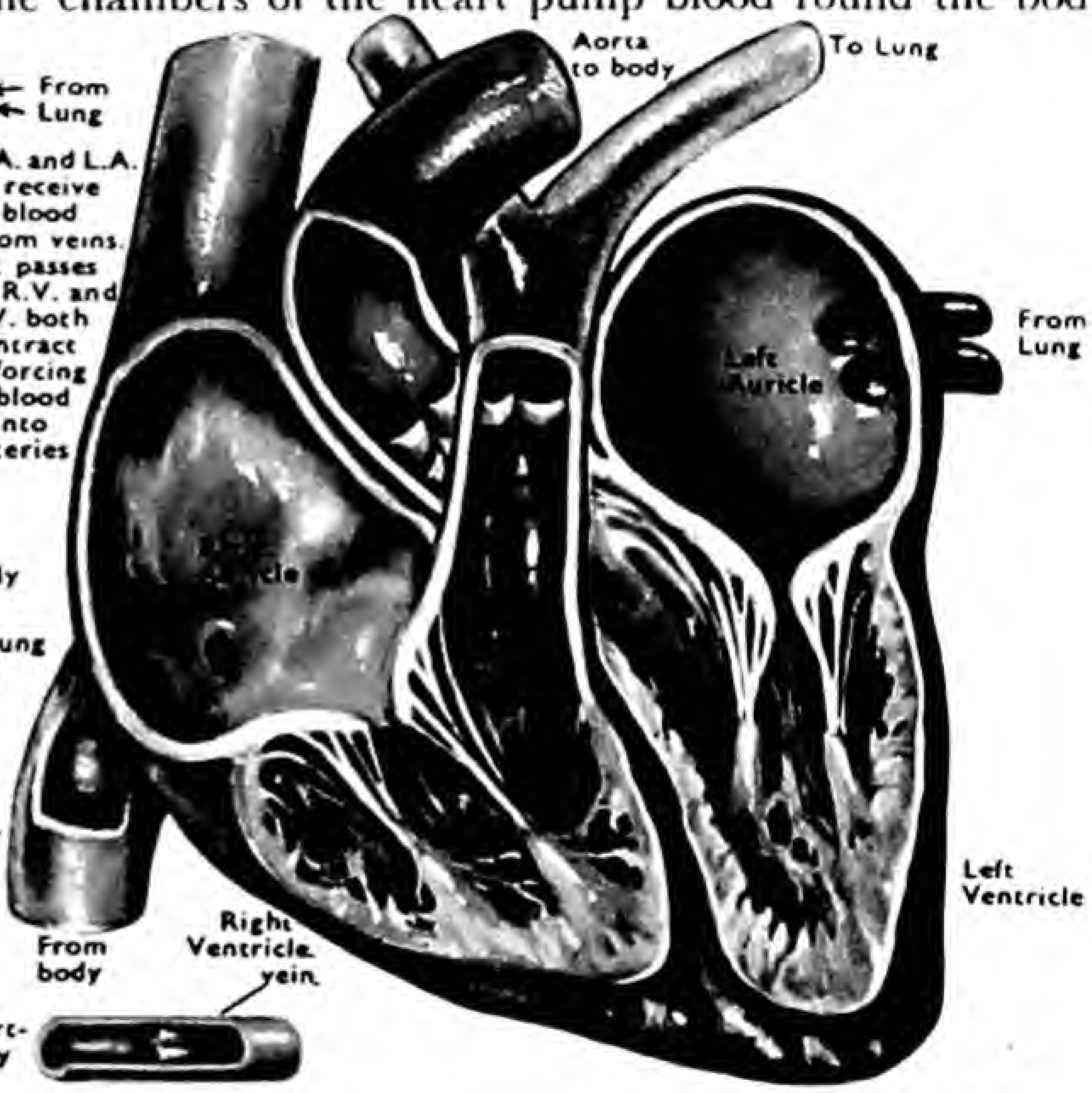
The Human Heart

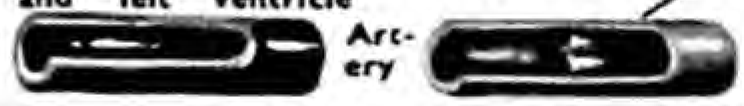
The heart is a part of the blood vessel system where the walls are very thick and muscular. It is the tensing and relaxing of these muscles which by altering the size of the chambers of the heart pump blood round the body.

The early anatomists found a whole system of hollow tubes, the arteries and veins, joined to the heart and containing the blood. They deduced that the heart is a specially elaborated part of the blood system, but its purpose (with which we are now all familiar) of pumping the blood round the body was something that by mere inspection they could not recognise. We now know that the arteries and veins make a loop because they connect through the tiny capillaries.

The system of blood vessels can be seen to be intimately connected with all parts of the body, gut, liver, brain, muscles, kidneys, lungs, etc. But the early anatomists by mere inspection could only guess vaguely at how it operated in the living body.

The muscles of the heart contract its four cavities in this order, valves between them make sure the blood flows correctly.
1. Right auricle and left auricle contract together.
2. Right ventricle and left ventricle contract together.





The arteries are tough to stand the pressure of the outgoing blood. The walls of veins are thinner for the blood in them lacks the same amount of pressure. Cone shaped valves give the blood a one way flow.

The Food Tube

The food tube (gut) winds about inside the abdomen or belly.

One of the things which distinguishes animals from plants is that they swallow food and excrete indigestible waste. Anatomy shows that in the vertebrate, the food goes straight from the mouth along a tube of varying character which winds about inside the abdomen or belly. This is the gut or alimentary canal. By the time the food reaches the end of the tube it has been thoroughly altered by the digestive processes and only indigestible substances remain to be excreted as faeces or waste. What happens to the other part? Indeed why is it necessary to eat at all? Anatomy alone has to leave these as mysteries.

Physiology

The study of living animals is difficult, for the body of an animal cannot be taken apart like a machine without resulting in considerable injury or even death. So the early biologists had mostly to be content with what they could learn from the bodies of dead animals. This study of construction of animal bodies is called Anatomy. Enquiry into the processes by which the body functions as a going concern is called Physiology.

PHYSIOLOGY—The functioning of animals

By watching the slow heart beats of live cold-blooded animals, and by relating the pulse to the action of the heart, the Englishman Harvey in 1628 demonstrated that the movement of blood in the body was circular—the heart being a muscular pump filling the arteries and the veins returning the blood once more to the heart.

A stomach pump which extracts the contents of the stomach.

In 1791 Galvani, an Italian, showed that the application to the nerve of a frog of a stimulus (later discovered to be electrical in character) produced contraction in the muscle to which the nerve was connected. This contraction resulted in a "kicking" movement executed by the limb of the frog.

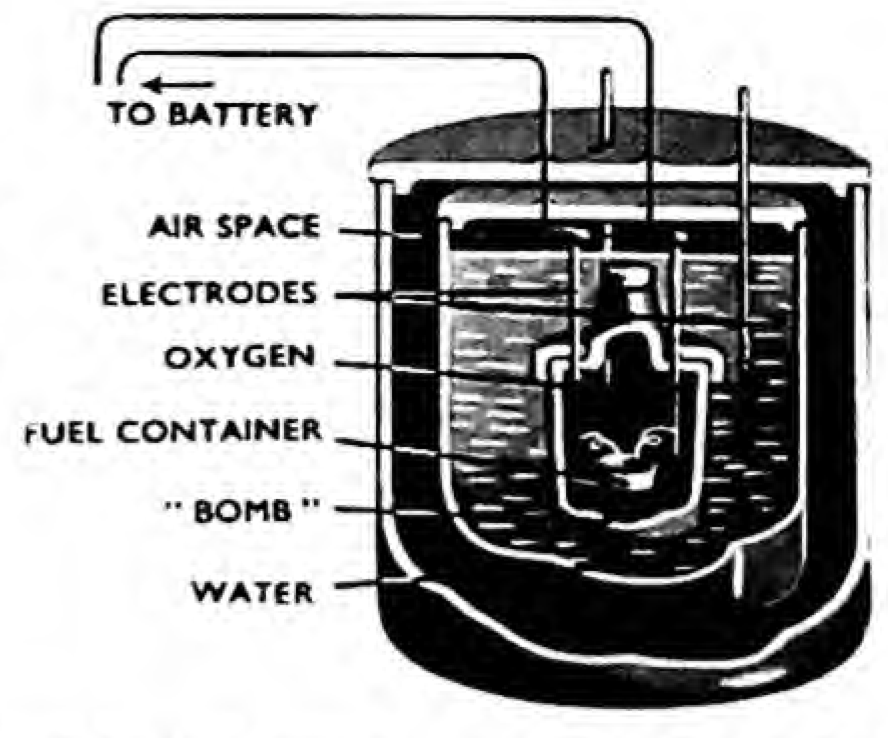
Research on digestion

Why do animals need to eat? What exactly happens to the food as it goes through the alimentary canal? And why does the waste weigh less than the food. Where does the rest of it go?

It is impossible to make chemical analyses in a living animal's stomach, but the stomach pump enables the biologist to get food out of the stomach at differing times after digestion has started.

When analysed, the half-digested food shows that it is being broken down by enzymes which are formed in the stomach wall. Biologists managed to extract and purify these enzymes. The principal one in the stomach is pepsin, activated by hydrochloric acid which too is secreted by the stomach lining.

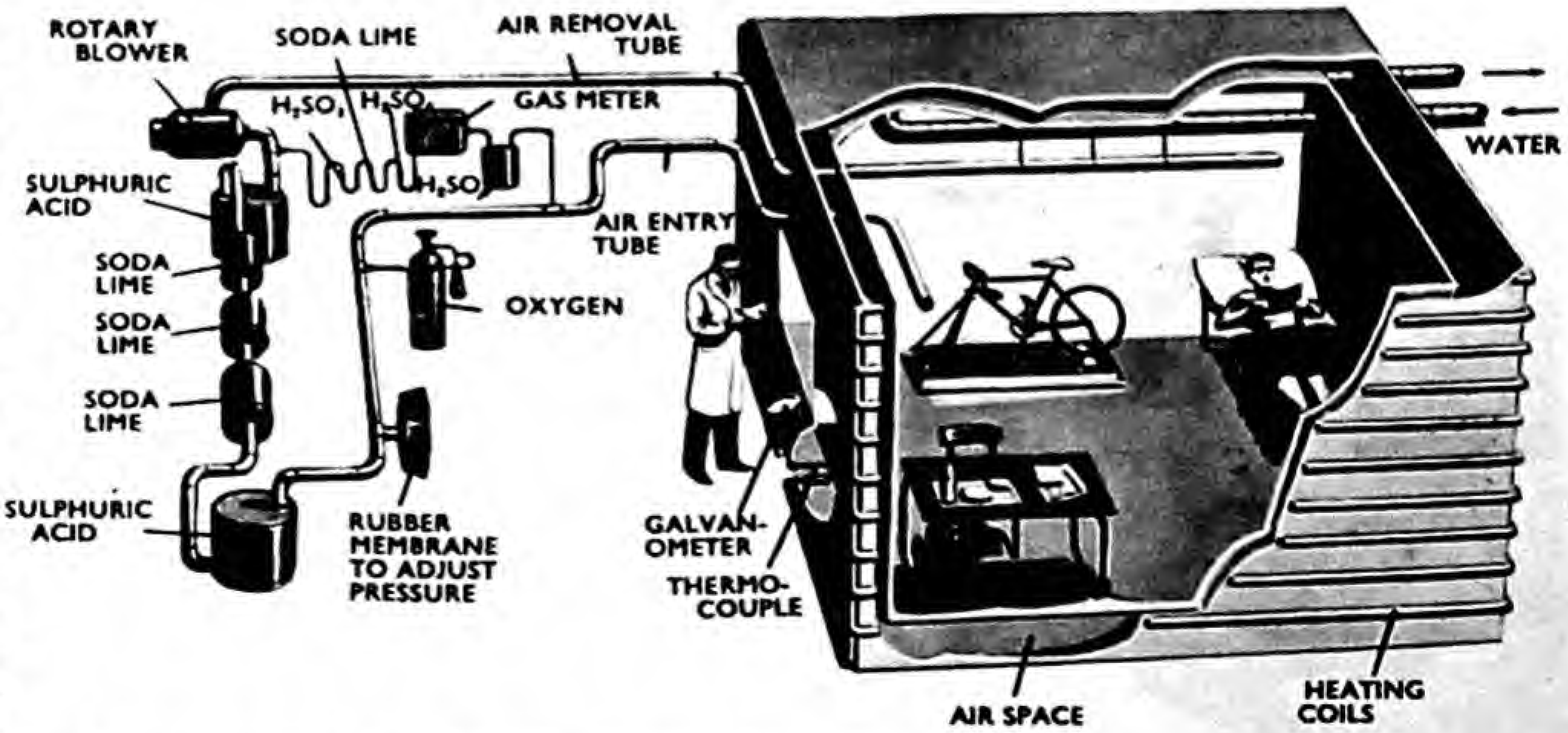
The "bomb" calorimeter measures the heat produced when a substance is burned.



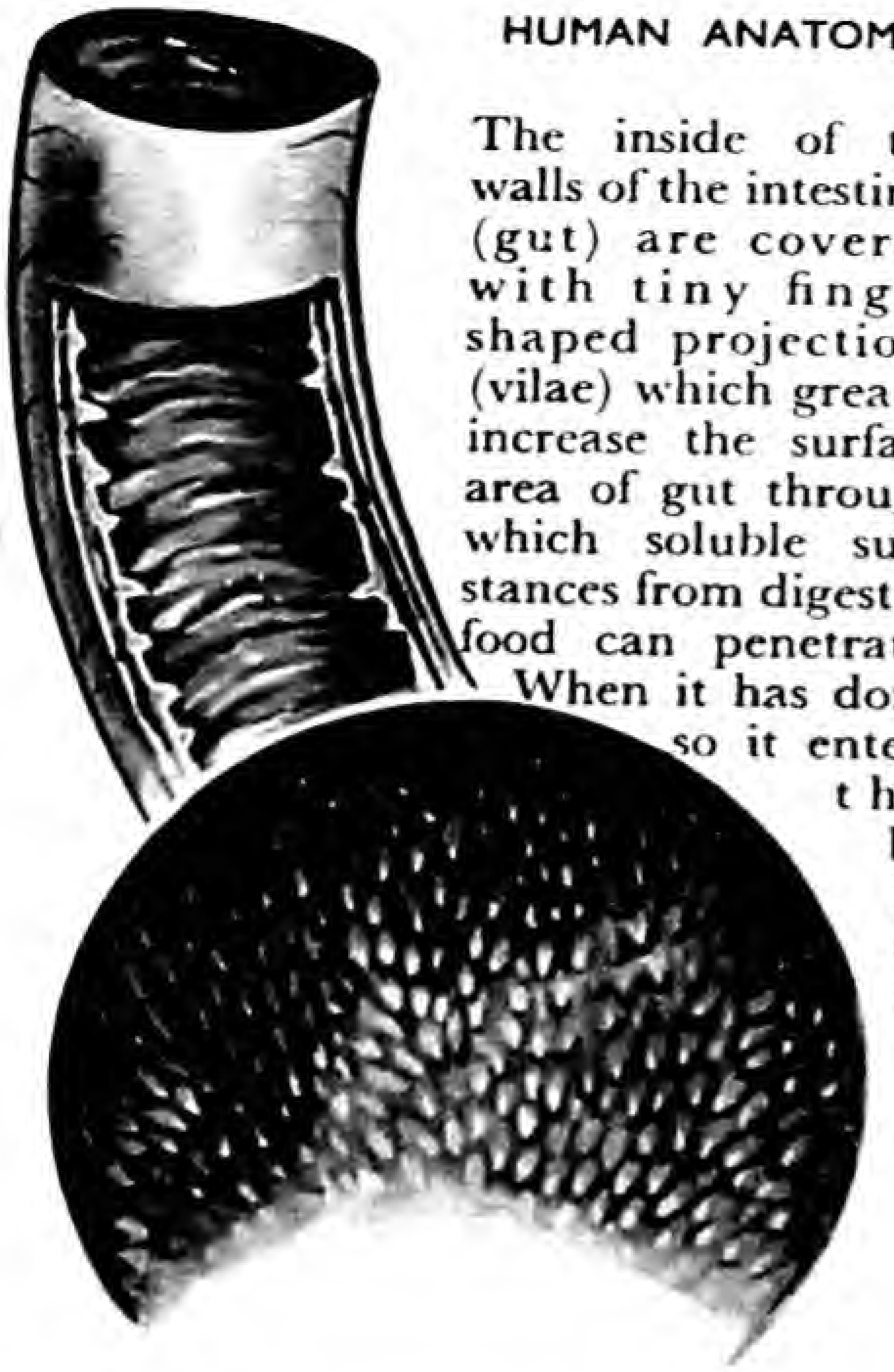
A piece of hard boiled egg can be put into a test tube with a dilute solution of extracted pepsin and a few drops of hydrochloric acid. If kept at blood heat artificially the egg can be seen gradually to be eaten away and turned into a sludge by the enzyme action. The products on analysis prove to be a number of simpler and soluble substances known as amino acids. Where do these amino acids go then now that the stomach has taken so much trouble to produce them from food? The answer strangely enough is *through* the gut wall into the circulating blood stream. This can be proved by putting some sugar on to a piece of gut stretched across the surface of pure water. The water below becomes sugary.

Starchy foods are digested in the bowel by appropriate enzymes and turned into blood sugar (glucose), which too can pass through the gut wall. The part of the food that resists the action of the animal's enzymes remains insoluble, cannot therefore be absorbed and passes on to accumulate in the rectum as waste.

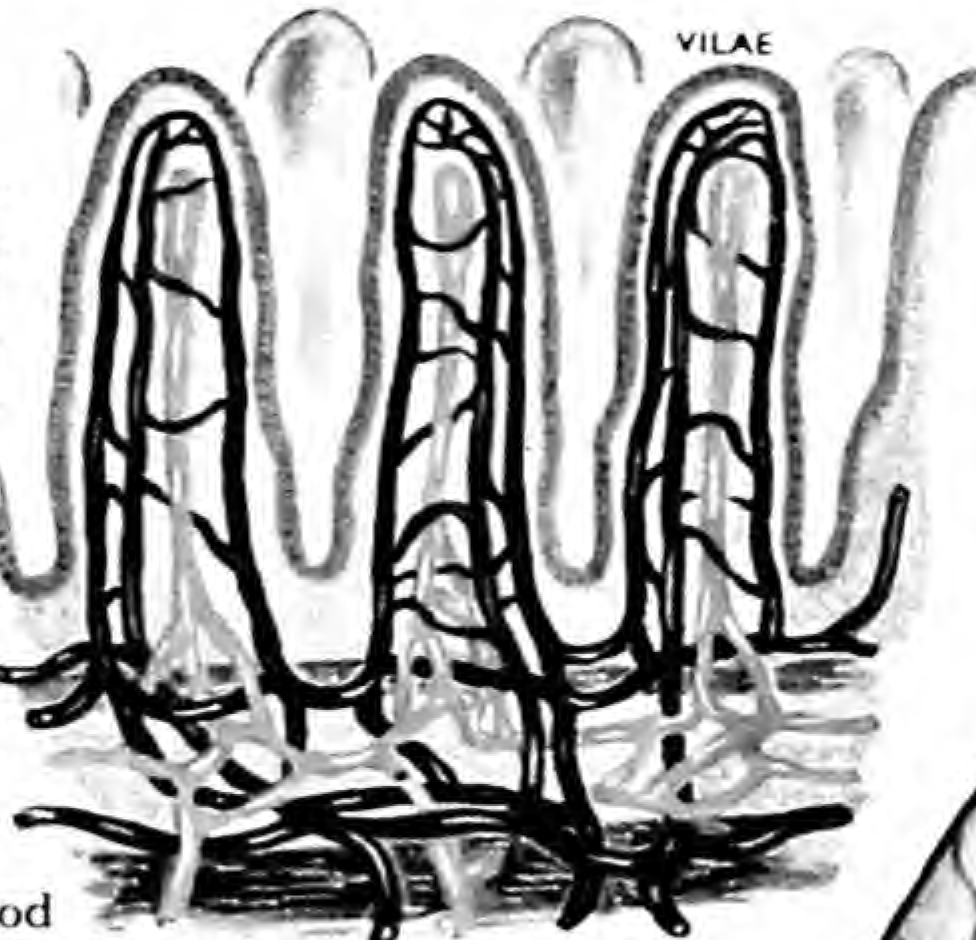
It is possible to withdraw blood samples from the blood vessels leading way from the gut to the heart.



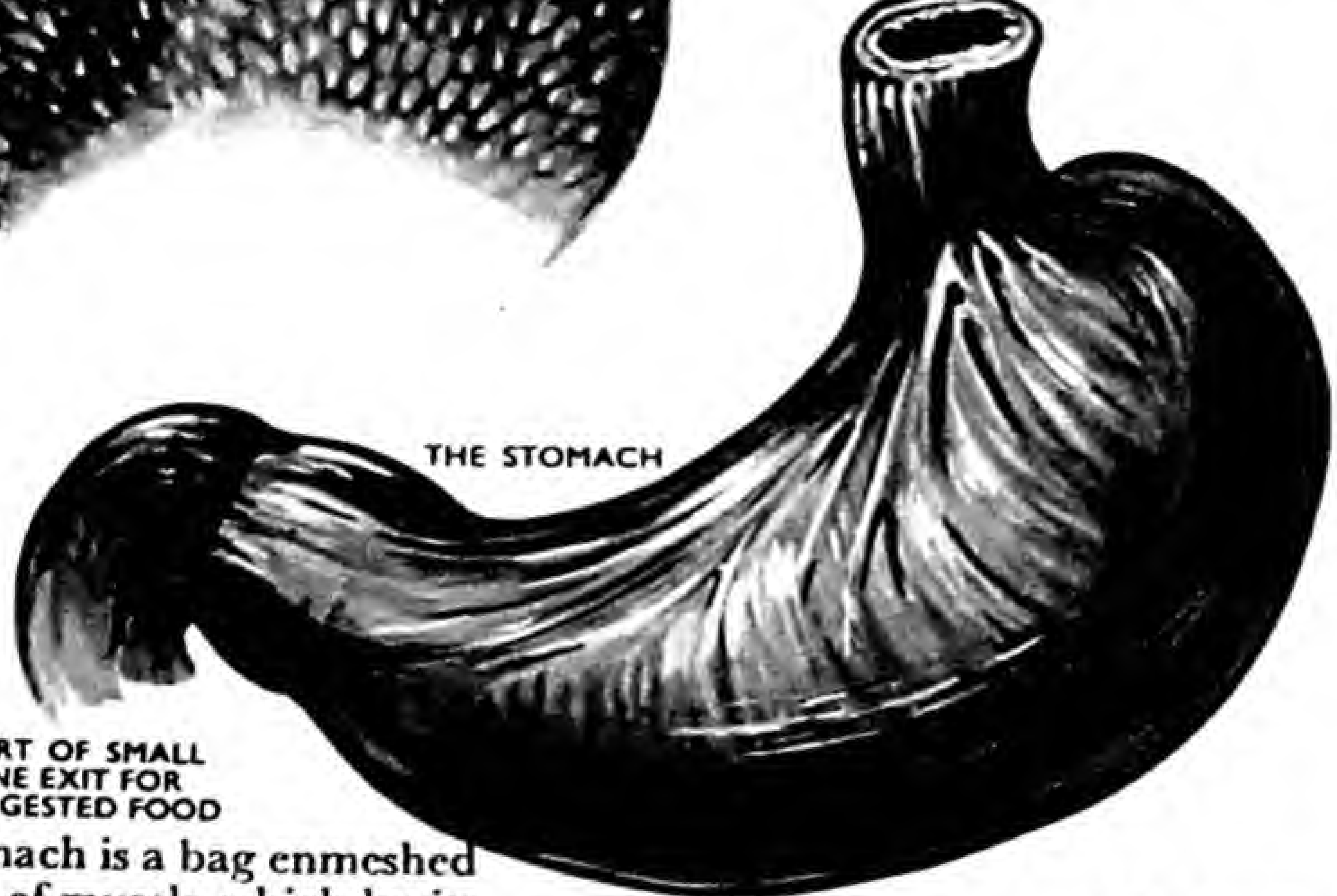
A calorimeter large enough to contain a man. Heaters between the walls exactly make up the loss of heat so that the rise in temperature of the water in the pipes shows the amount of heat given off by the man when working and when resting.



The inside of the walls of the intestines (gut) are covered with tiny finger shaped projections (vilae) which greatly increase the surface area of gut through which soluble substances from digested food can penetrate. When it has done so it enters the blood in the big vein of the vilae and is carried away through the Portal vein to the liver.



Peristaltic action of the intestine. Muscular contractions squeeze the waste along towards the rectum.



The stomach is a bag enmeshed in sheets of muscle which by its pattern of flexing and unflexing mixes the food thoroughly with the digestive juices the stomach contains.

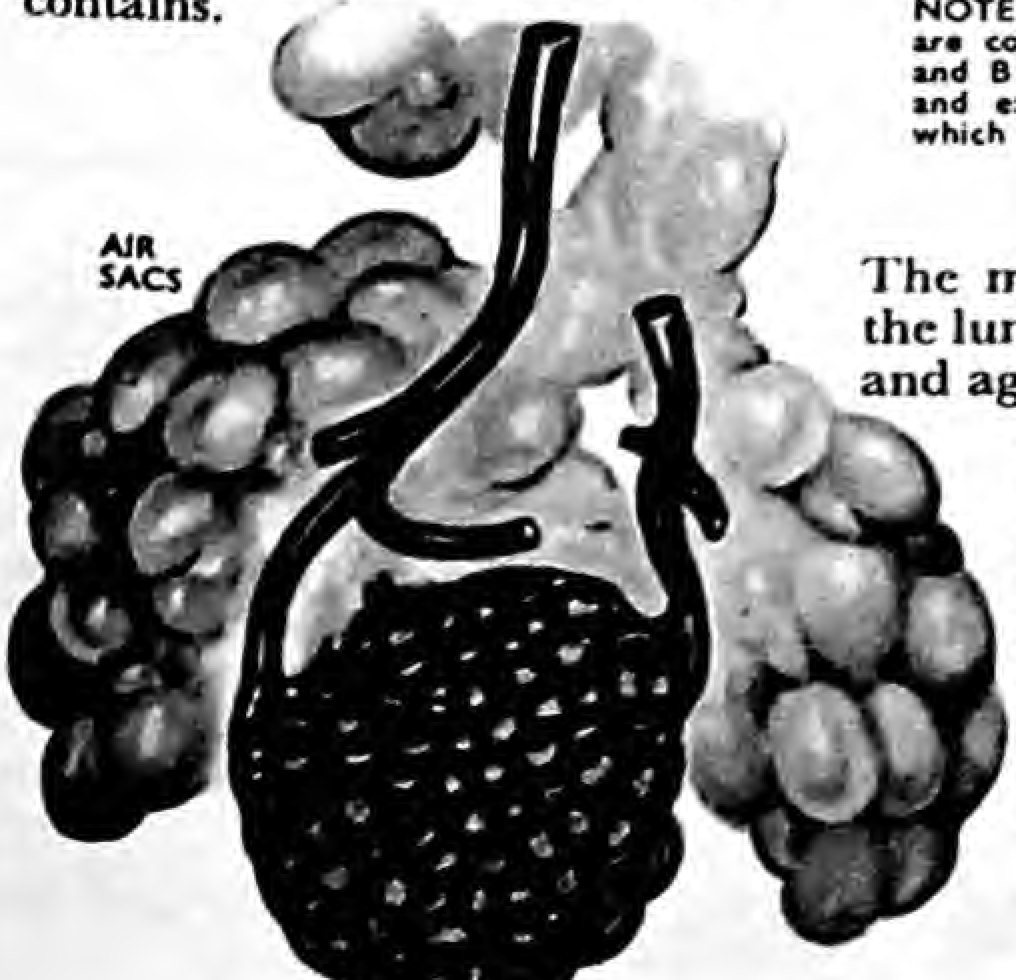
The abdominal and chest cavity. The organs in life are fitted in one behind the other, but have been drawn aside to make them easier to see in this drawing.

LUNGS

This part of the picture has been turned like the left hand page of a book to reveal the kidneys and bladder.

NOTE . A A (the intestine) are continuous in reality, and B B are the entrance and exit of the stomach which has been removed.

A B A



The main air tube to the lungs divides again and again until it ends in tiny air sacs in each lung. In the wall of the air sac is a capillary network where gas exchange takes place through the wet wall.

Some while after a meal has been taken and when digestion has progressed far enough, the blood in these vessels is found to have an increased sugar content.

Of what use is the sugar from digestion to the animal's body? Chemists have shown with instruments like the bomb calorimeter that if a certain amount of sugar was combusted or burned, it gave off a corresponding amount of heat, just as burning coal does, since both sugar and coal are compounds of carbon. So biologists measure the heat given off by living bodies in order to investigate the intensity of the body's activity in combustion. The apparatus used for measuring the amount of heat given off by something burning is called a calorimeter. It is usually a copper pot, with an insulated lid, surrounded by a chamber in which cold water runs and collects the heat given out in the calorimeter. Knowing the number of degrees through which the water is heated by reading thermostats in the water inlet and outlet and the amount of water that has passed it is possible to calculate the amount of heat liberated by the combustion and received by the water. A giant calorimeter as large as a small room is used to check the heat given off by the human body. Even at rest this is considerable, since man is a warm-blooded animal; when at work it is very much greater in proportion to the mechanical effort of the work done. If the person whose body heat is being examined has not had a meal before doing the test work he loses weight after doing it. Measurement at the same time of the gas exchange due to breathing (*see later*) also help to show that the principal substance being burned in the body is sugar.

THE LIVER—A storage Tank for Sugar

Tests of the blood composition in the body generally show that, as long as the person concerned did not have a disease like diabetes, the blood sugar content remains very steady even during digestion. This, as we have seen, is not true however for the blood in the portal vein coming away from the gut. The organ responsible for this effect was found to be the liver. The portal vein takes the blood from the gut wall not directly to the heart but to the liver. From this organ it then passes separately to the heart. The sugar content of blood passing from the liver to the heart keeps at a steady level. Detailed investigations have shown that the liver takes sugar from the blood during digestion when it is above the normal level and stores it as a system of oily drops of glycogen. Later during exertion or fasting, this glycogen is converted back to sugar which makes up any sugar deficiency in the blood at such times. These changes can be followed by chemical analysis of the liver of animals.

WASTE SUBSTANCE IN THE BLOOD

Amino acids from the digestion of protein foods, e.g. egg, meat, cheese, milk, are used for body building, but any excess of them can be converted in the liver into sugars with the simultaneous formation of ammonia. This last substance being poisonous is converted (also in the liver) to urea which then enters the blood stream. The nitrogenous substance is a typical end product of protein usage in the body, just as carbon dioxide and water are the products of sugar combustion. These end products are, unlike the faeces, soluble wastes in the blood stream—the "ashes" of the sugar burned up by the blood work. They have to be passed out of the body by special means.

WHAT THE KIDNEYS DO

Urea is "filtered" out of the blood by the action of the kidneys. These organs are supplied with blood on a "by-pass" loop (the same sort of idea as the oil filter in a car engine), so that a proportion of all the blood circulating goes through them. Chemical tests show that the kidneys allow the urea to pass through them in solution in water taken from the blood. This goes into ducts or tubes which discharge the solution as urine into the bladder from which it is eventually eliminated from the body.

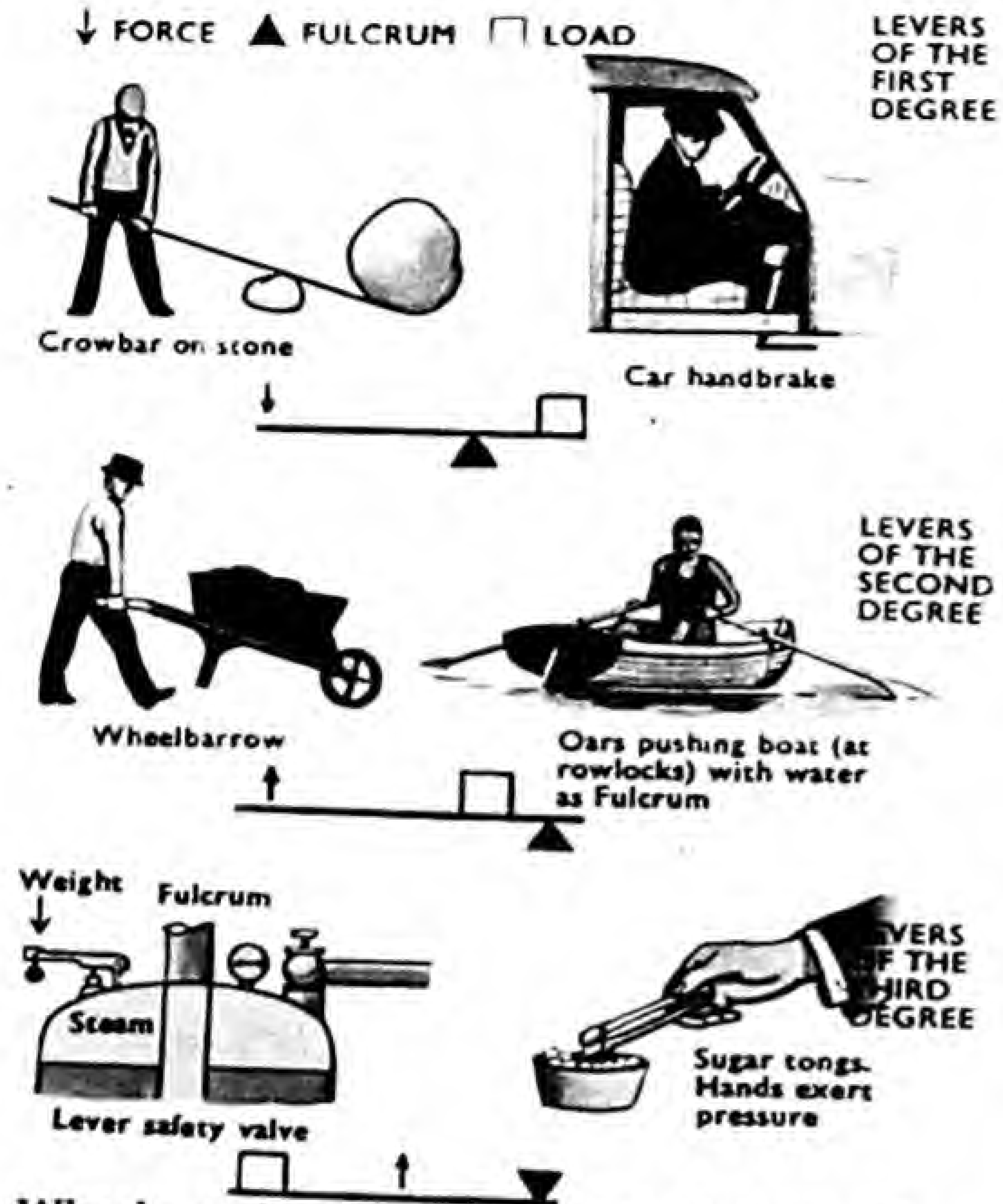
HOW THE LUNGS GET RID OF CARBON DIOXIDE

The drawings on page 69 explain how air is mechanically forced into the lungs by the muscles of the rib basket and all of the diaphragm. The biologist calls that process breathing. Respiration is the name he gives to the chemical process of combustion in the body tissues.

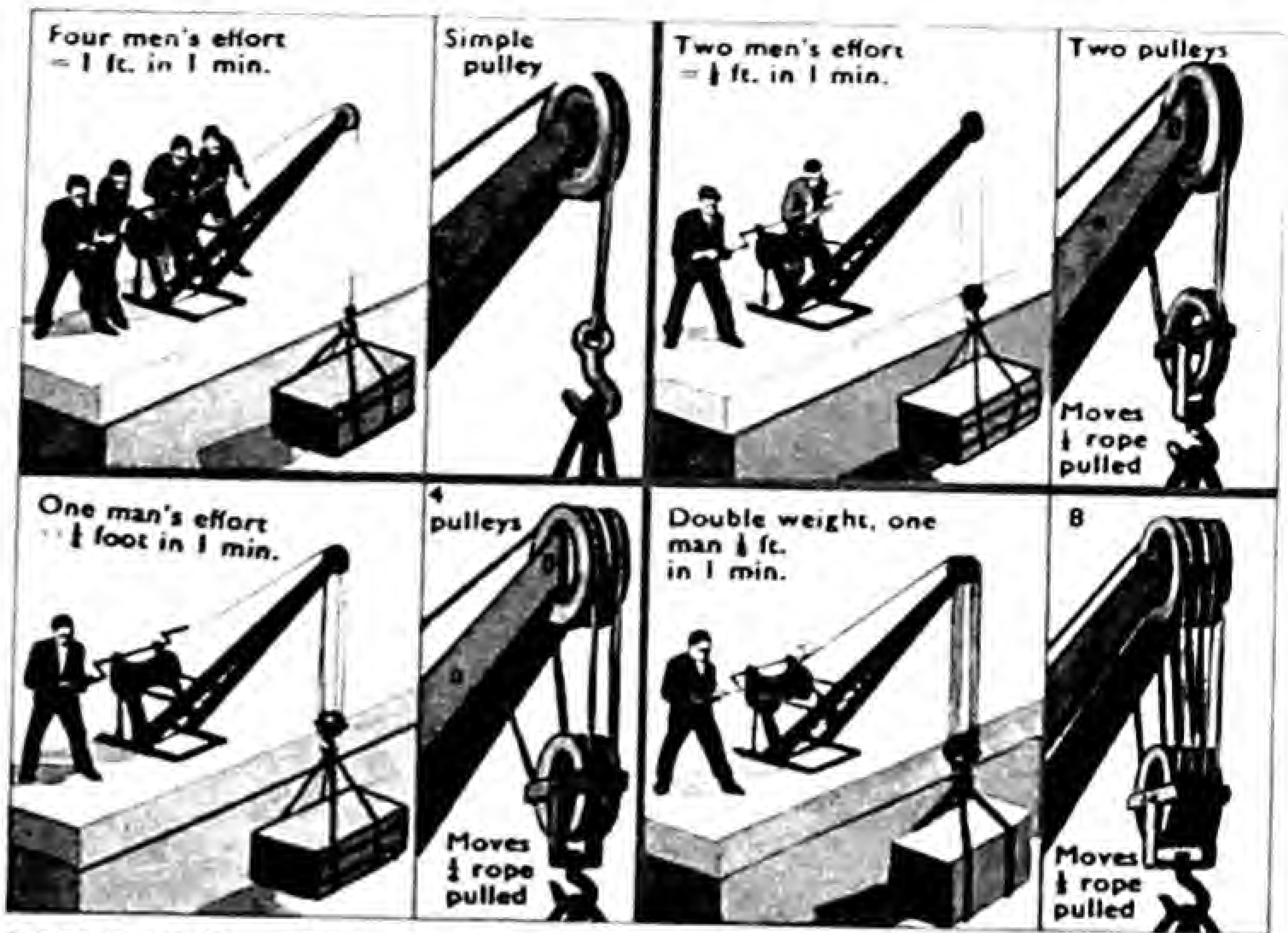
The amount of oxygen extracted from the air taken in during breathing can be measured, using an air bag apparatus to collect the gases breathed out. The composition of the intaken air is of course known. Analysis shows that for every volume of oxygen removed from the air during breathing an equal volume of carbon dioxide is returned into the expired air. The air breathed out is thus richer in carbon dioxide and poorer in oxygen than fresh air. The amount of carbon dioxide in the blood is thereby kept level, this waste substance being passed out as a gas through the walls of the lungs.

MACHINES THAT CONCENTRATE ENERGY

Machines do not by some magic create energy, the amount of work a machine does is the same amount as is put into the machine. Its usefulness is that it enables a lot of movement with a little force to be converted into a little movement with a lot of force. The main types of machine (that is apparatus for concentrating energy) are Levers (a bar free to move over a pivot) ; wheels and axles (a form of lever, the fulcrum is the axle) ; cranks (e.g. an oblique force applied to a wheel lever, see p. 34). Pulleys (which divide the load among the ropes running round the pulleys) ; Gears (pages 42, 43). Inclined planes (on which the weight of a load is balanced by a lesser vertically hanging weight, all screws are spiral inclined planes).



Wheels and axles are a special form of lever, the fulcrum (axle) being turned by moving the outside of the wheel, its diameter is the lever. Capstan and single spoke wheel show lever action clearly.



PULLEYS. This looks as if pulleys save work—they don't really, you have to pull the end of the rope twice as far as if the pulleys halve the force needed, so you end up doing the same amount of *work*. The simple pulley saves no force, just changes its direction. The rope running round two pulleys only raises the bottom pulley 6 ins. for each 1 ft. of rope pulled.

Left: Longer spokes give greater leverage.

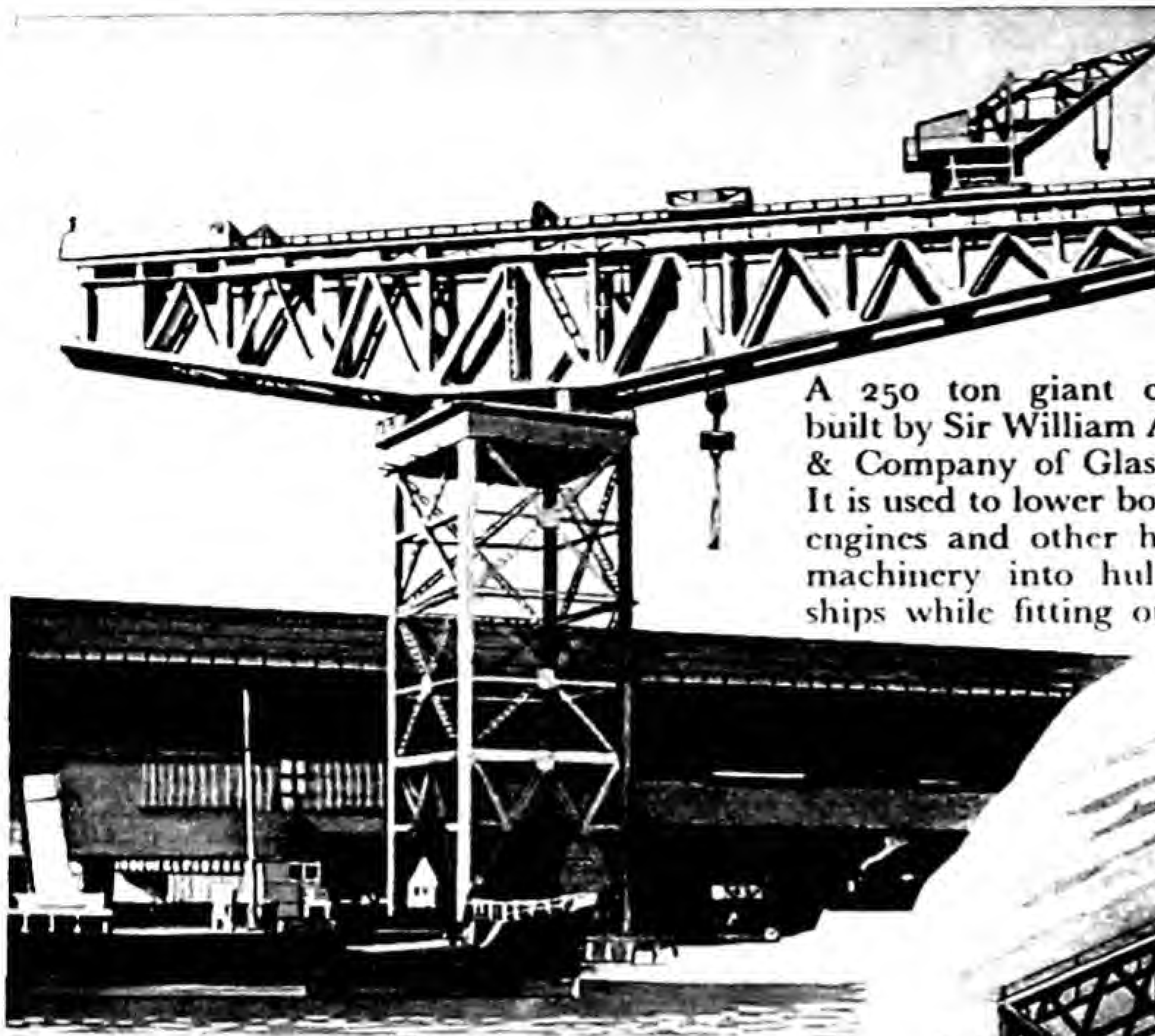
One spoke steering.

Right: Press worked by screw jack.

Car jack. Flange inside cog turns and pushes screw up.

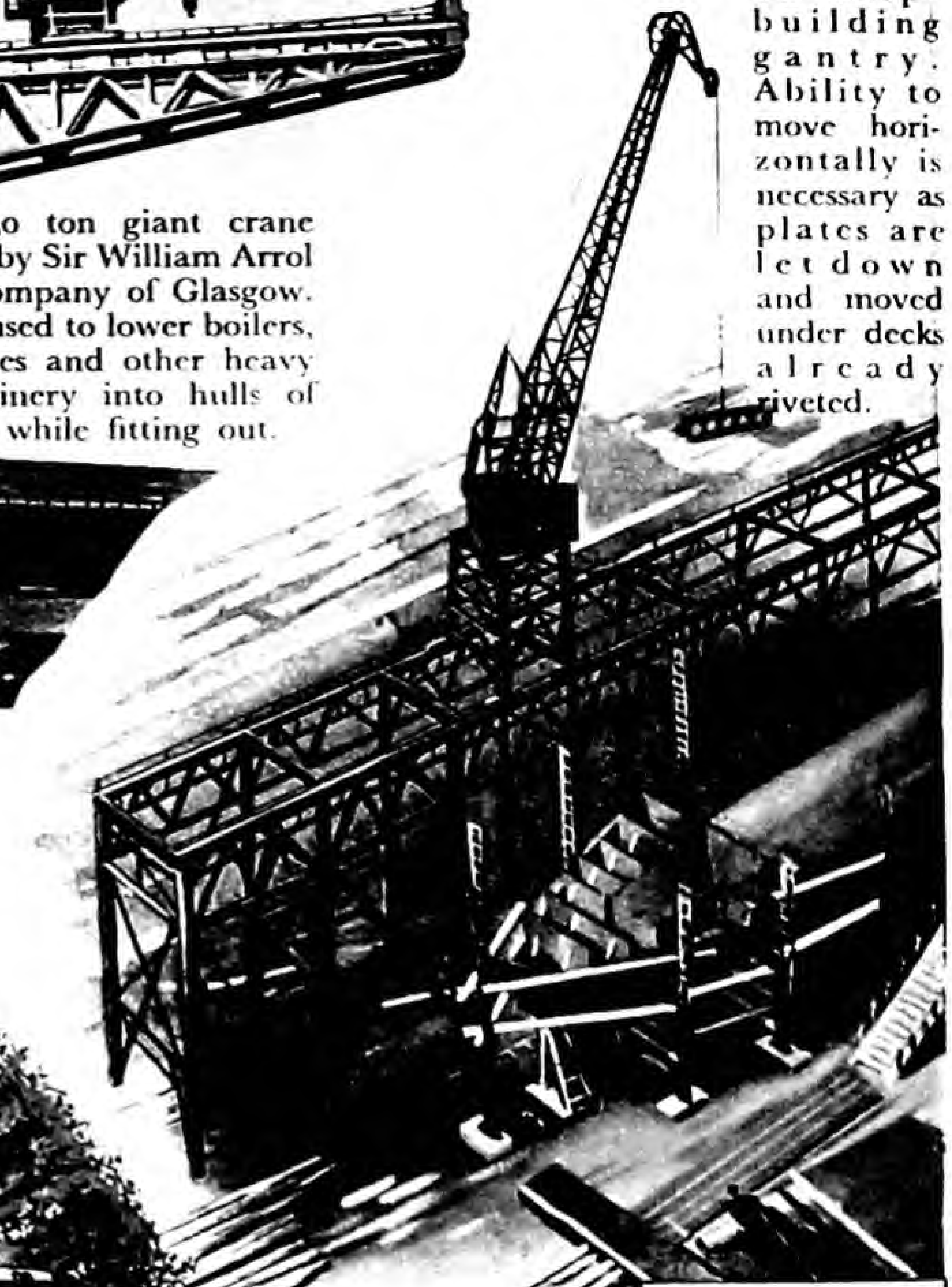
Below and *right*, lifting a house with a screw jack. Like a car jack but has lower gearing between lever and screw.

Tar barrels are easier to roll up the plank than to lift straight up—the work done is the same.

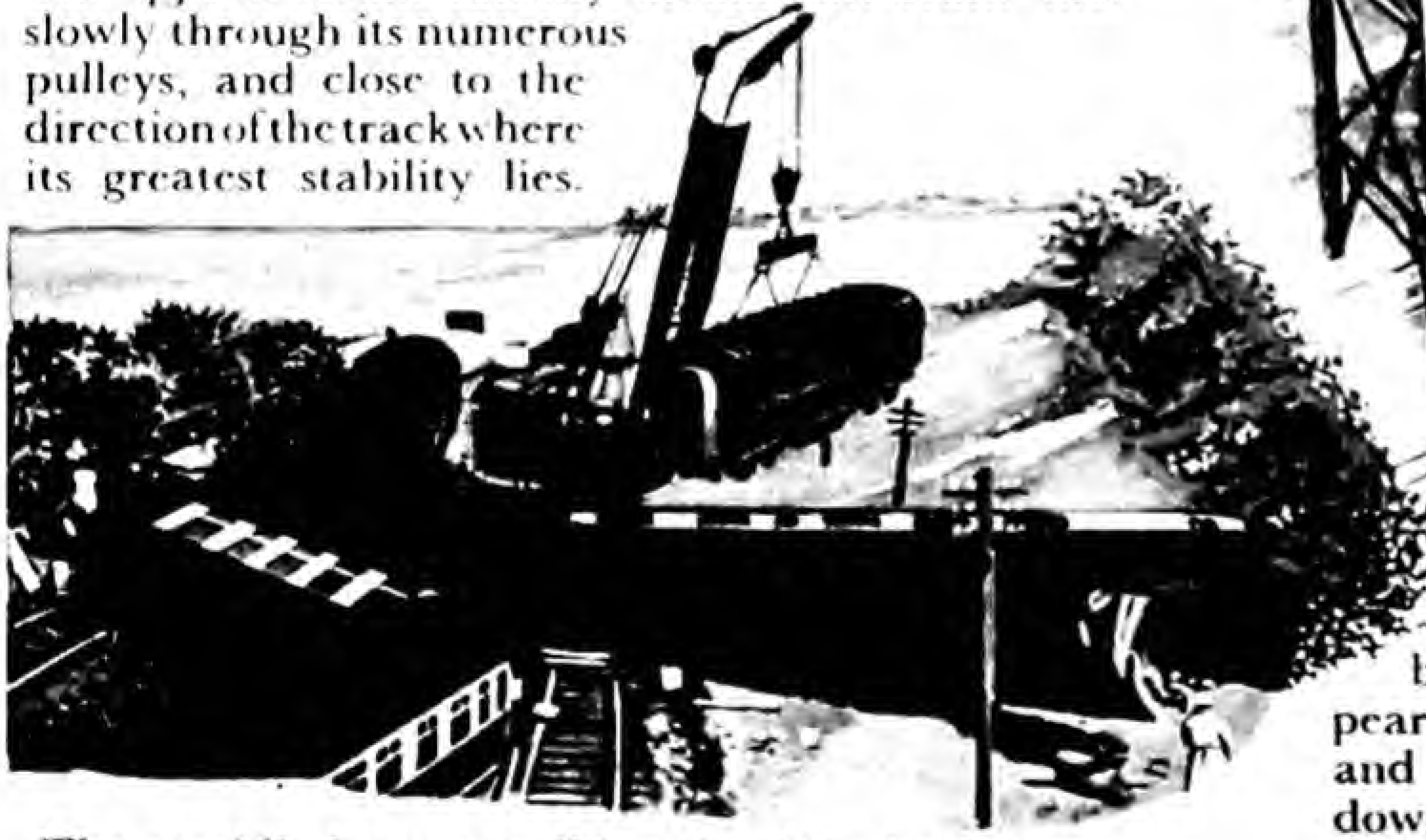


20 ton jib crane for **lighter loads** at the **fitting-out basin.**

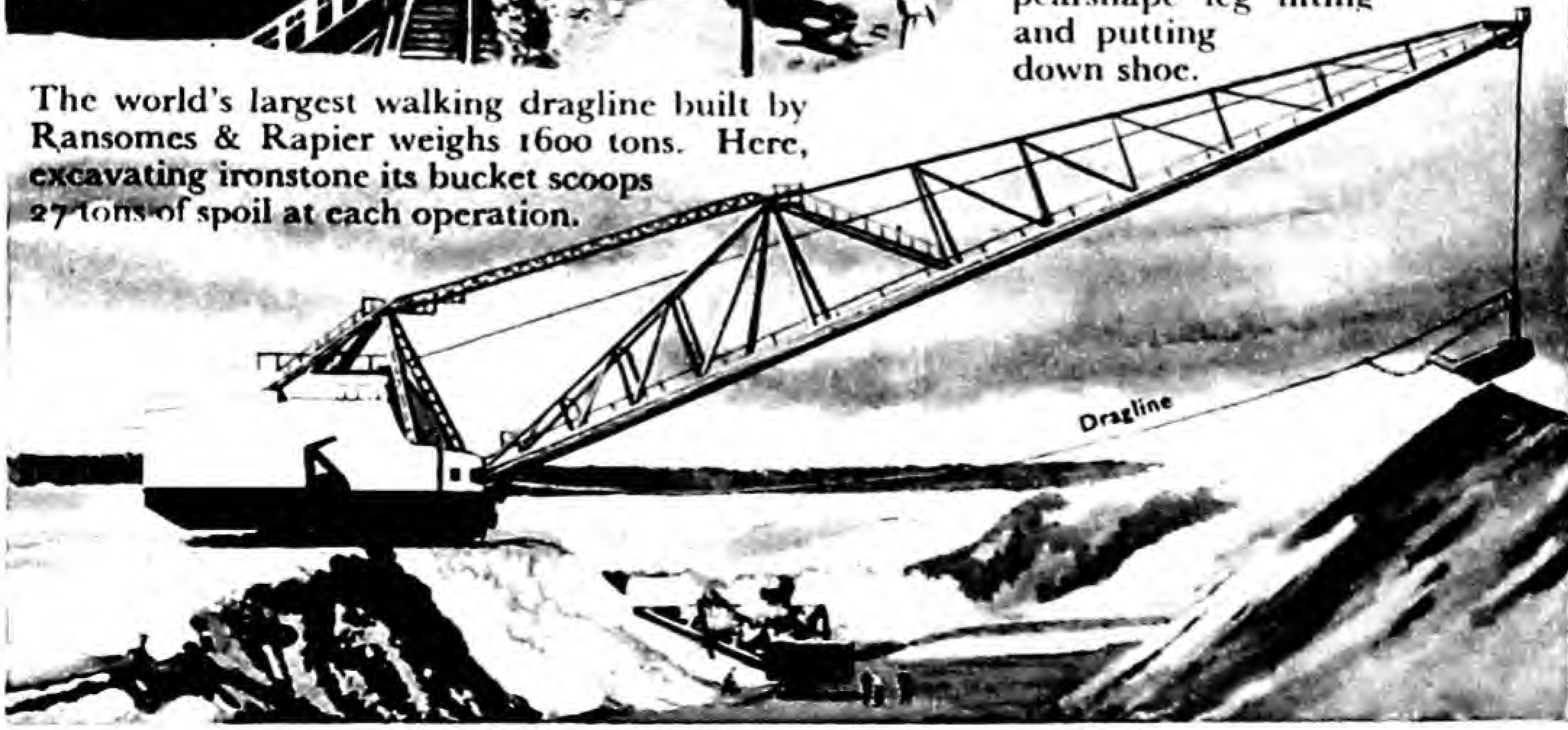
A 250 ton giant crane built by Sir William Arrol & Company of Glasgow. It is used to lower boilers, engines and other heavy machinery into hulls of ships while fitting out.



Babcock & Wilcox level luffing crane on ship-building gantry. Ability to move horizontally is necessary as plates are let down and moved under decks already riveted.



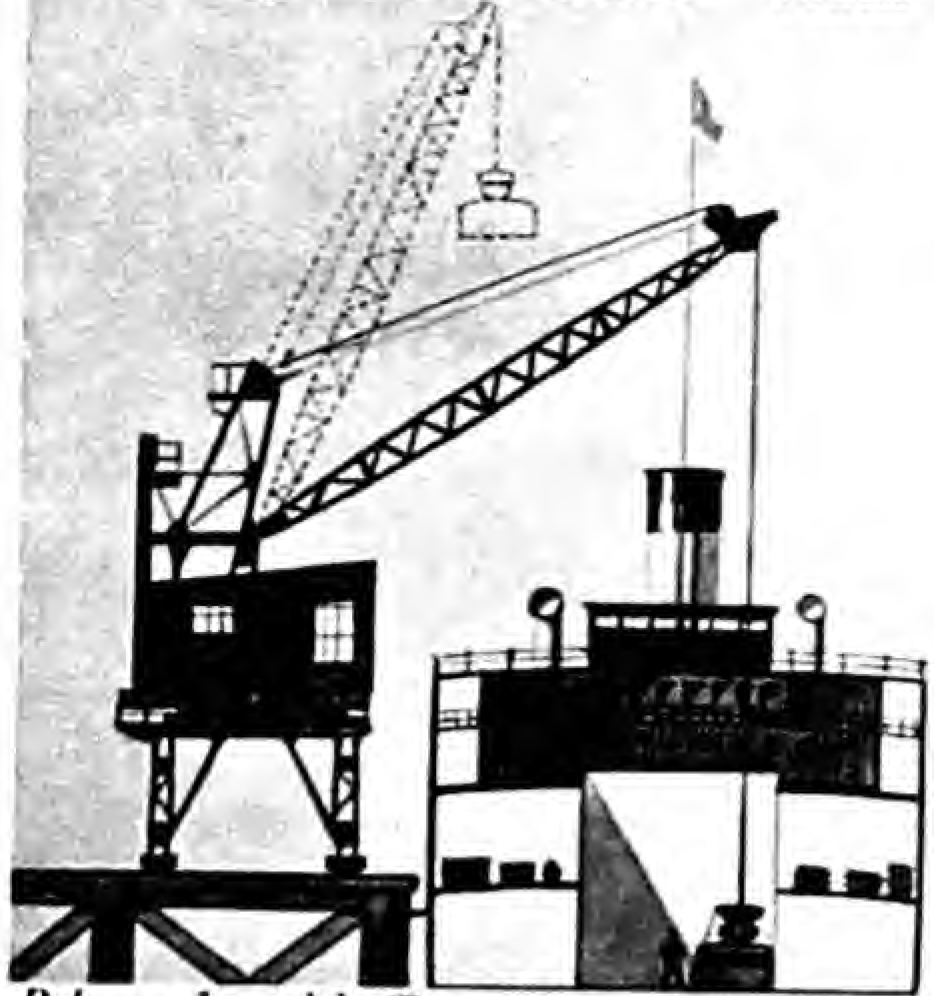
The 45-ton steam railway breakdown crane lifts slowly through its numerous pulleys, and close to the direction of the track where its greatest stability lies.



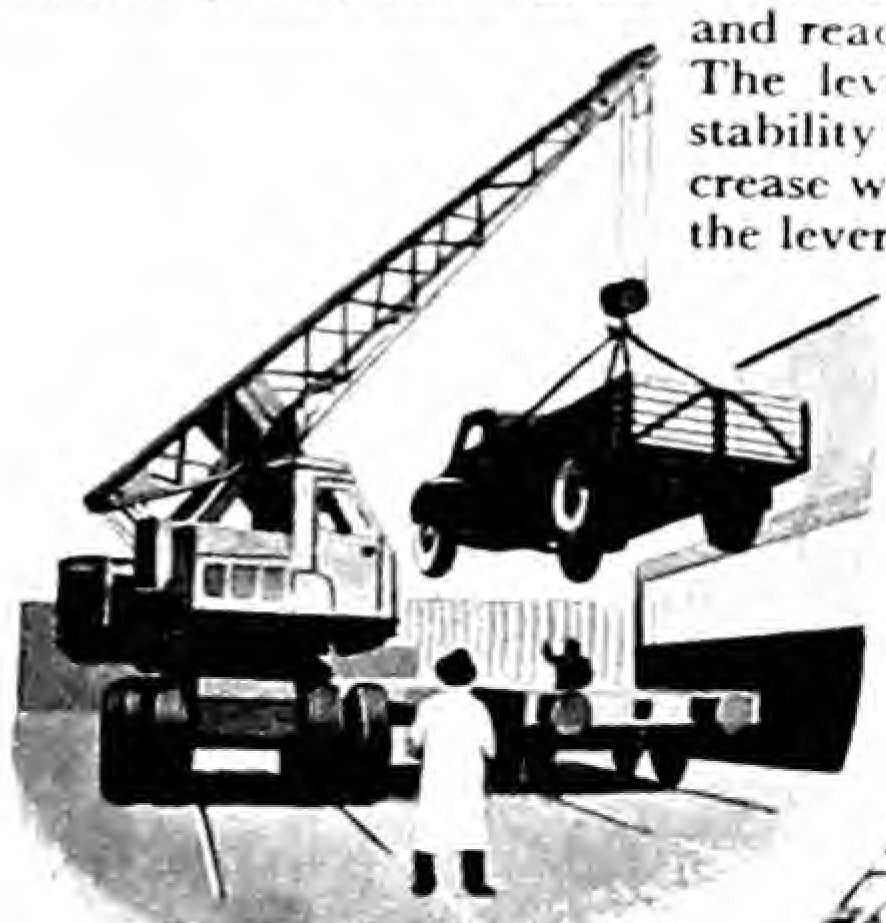
The world's largest walking dragline built by Ransomes & Rapier weighs 1600 tons. Here, excavating ironstone its bucket scoops 27 tons of spoil at each operation.

Walking dragline moves by the eccentric centre of pearshape leg lifting and putting down shoe.

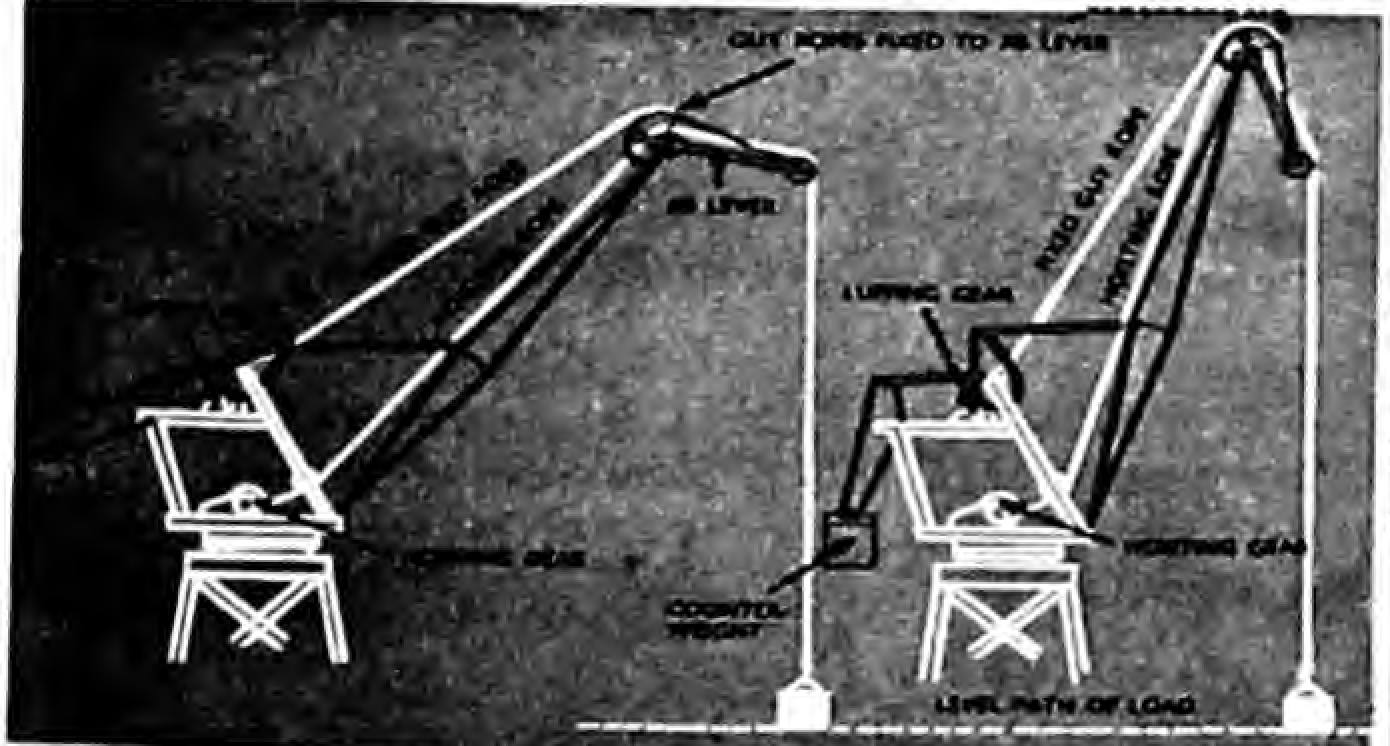
Quayside crane with separately controlled jib has a variable "reach".



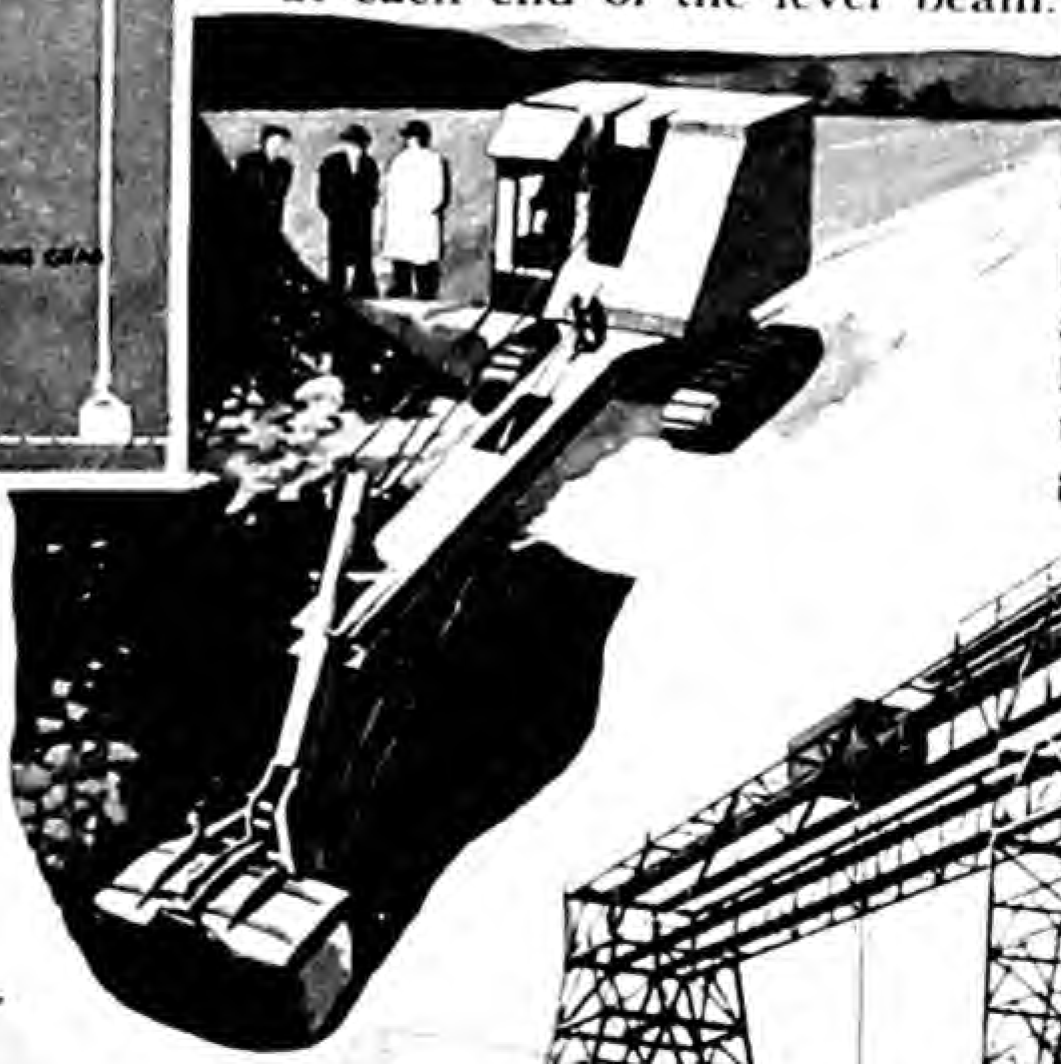
This mobile crane using its standard jib has a lifting capacity of 10 tons (*below*) but with the extension jib fitted to increase its height and reach its maximum load is 2½ tons. The leverage of the load against the stability of the crane increase with the length of the lever (jib).



Below : Level luffing crane. The luffing jib separately controlled to compensate for changing height of top of main jib.

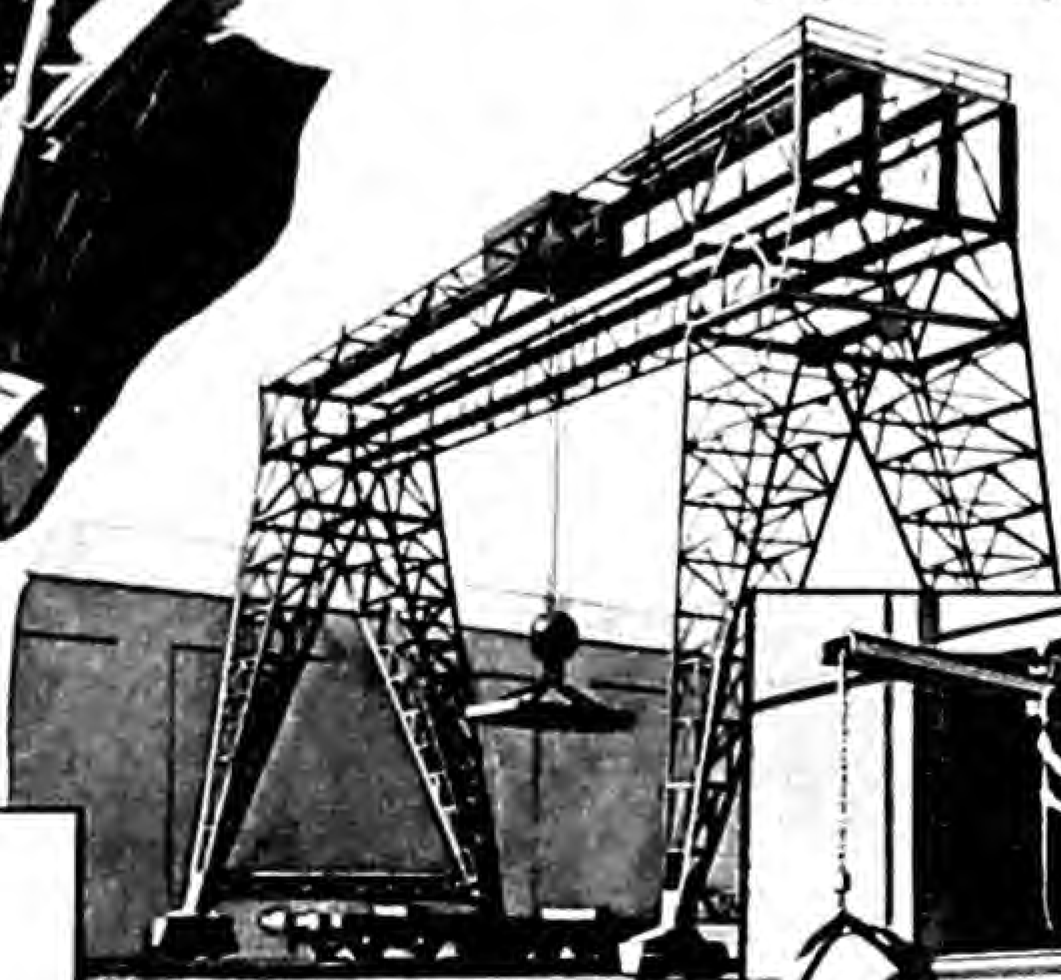


Below : Excavator bucket is swung to make its bite by pulleys and wires at each end of the lever beam.

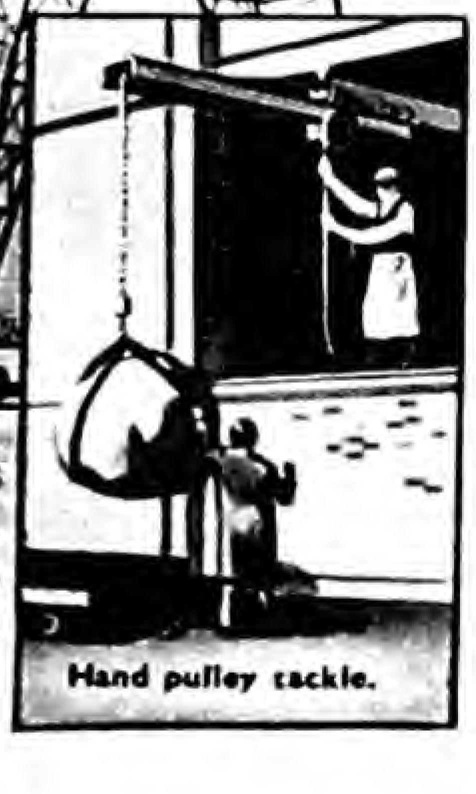


This lever hoist lifting a tractor is a hand tool which levers the chain through rachet grips link by link.

Giant travelling mineral loader straddles railway track.

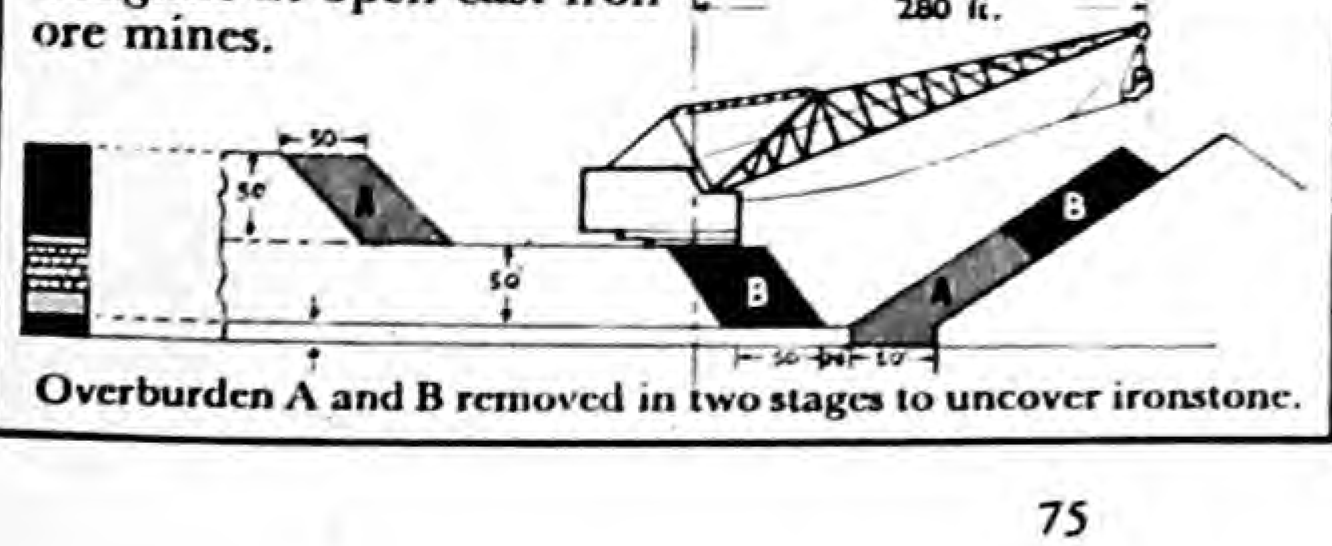


Above : 25 ton Morris Goliath travelling crane. The grab runs to and fro on the 100 ft span, which itself moves on rails.



Hand pulley tackle.

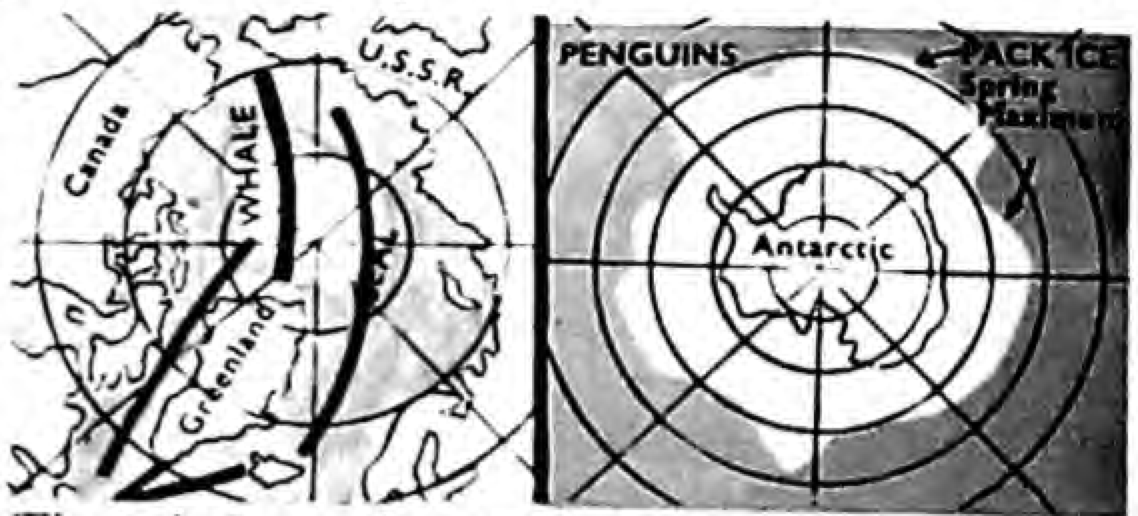
Dragline at open cast iron ore mines.



Overburden A and B removed in two stages to uncover ironstone.

ANIMALS AND BIRDS

The Greenland Seal ranges from the Atlantic to the Arctic migrating from north to south to breed.

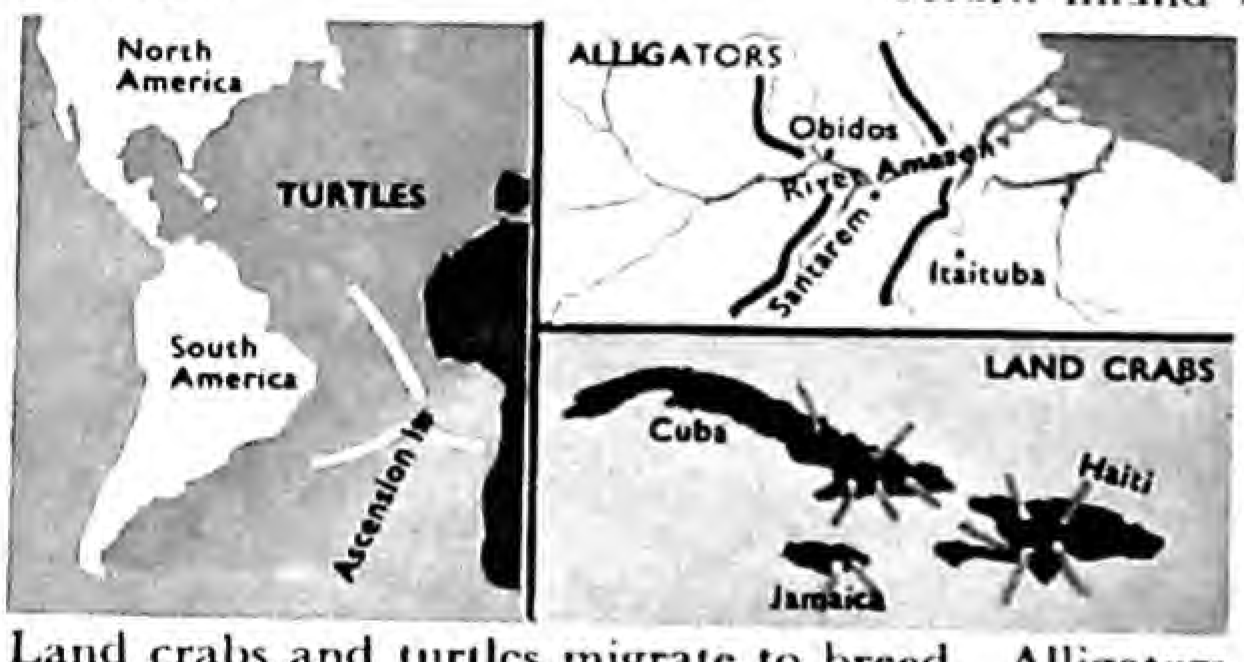


The whales and penguins migrate in search of food. The seals migrate to breed.

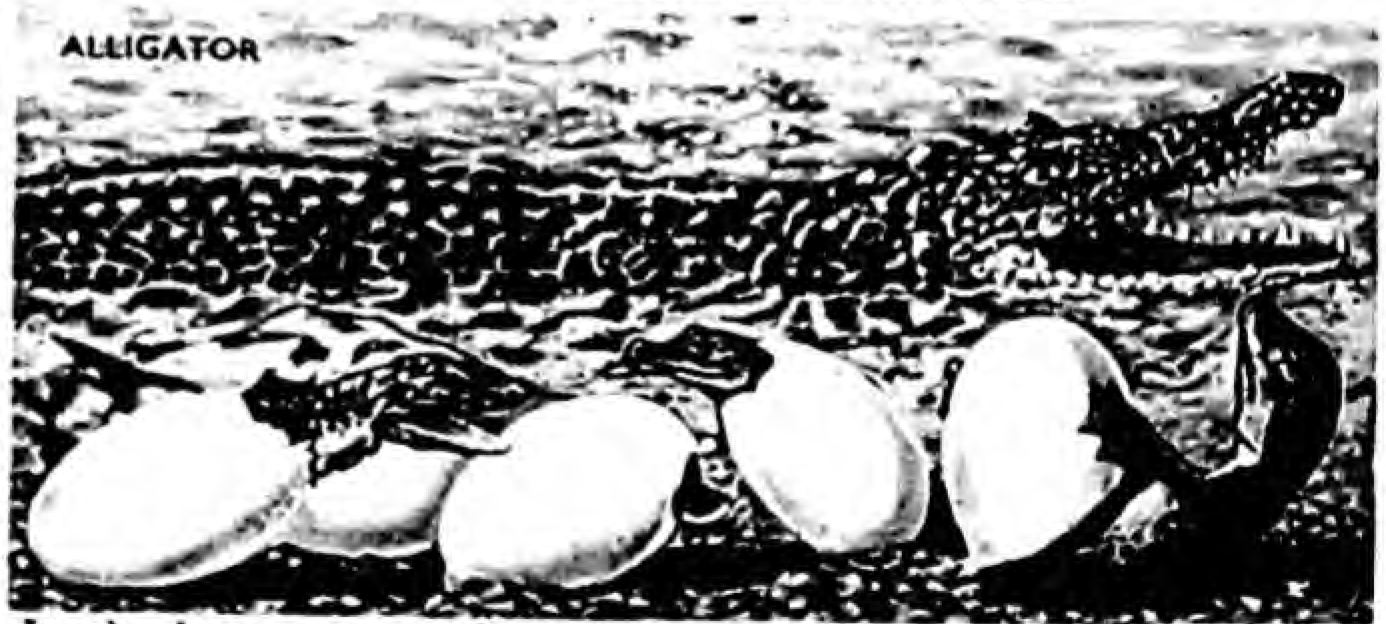
The Greenland Whale migrates north in the summer to feed in the polar seas and south in winter when young are born.

In winter Antarctic penguins migrate to the edge of the pack ice to reach open sea and food. In spring they return inland to nest.

The walrus inhabits the cold regions. In spring they herd, move south and give birth to young. They move north as the season advances.



Land crabs and turtles migrate to breed. Alligators migrate in search of water when it is scarce.



In the hot season, when the muddy pools dry up, S. American alligators descend to the main river.

Turtles inhabit tropical seas. They migrate to temperate waters where they land and deposit their eggs.

W. Indian land crabs live in the hills ; annually they descend to the sea in which the females lay their eggs.

THAT MIGRATE

See key below

Elephant migrations are local. They are connected with the search for food and with breeding habits.

In times of drought Springbok in S. Africa migrate to the Karroo in search of food.

They plunge in the sea only to drown.

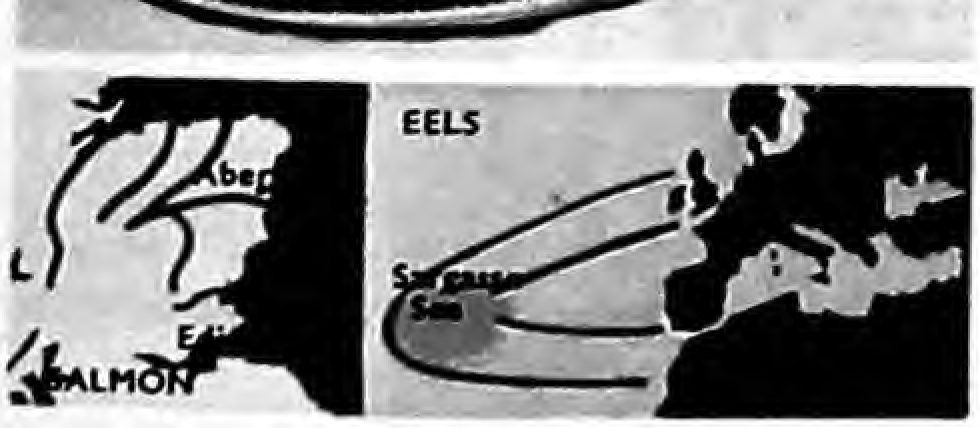
A sharp rise in population is believed to start the Lemming on its fatal journey to the sea.

1. Gold Crest. 2. Chiffchaff 3. Corncrake. 4. Yellow Wagtail
5. Turtle Dove. 6. Waxwing. 7. Swallow.
8. Roseate Tern. 9. Little Auk. 10. Little Tern
11. Red Backed Shrike. 12. Lapwing
13. Blackcap. 14. Kentish Plover. 15. Redwing.
16. Wood Pigeon. 17. Woodcock. 18. Kestrel.
19. Hooded Crow. 20. Mallard.
21. Dotterel. 22. Teal. 23. Redstart.
24. Song Thrush. 25. House Martin.
26. Skylark.

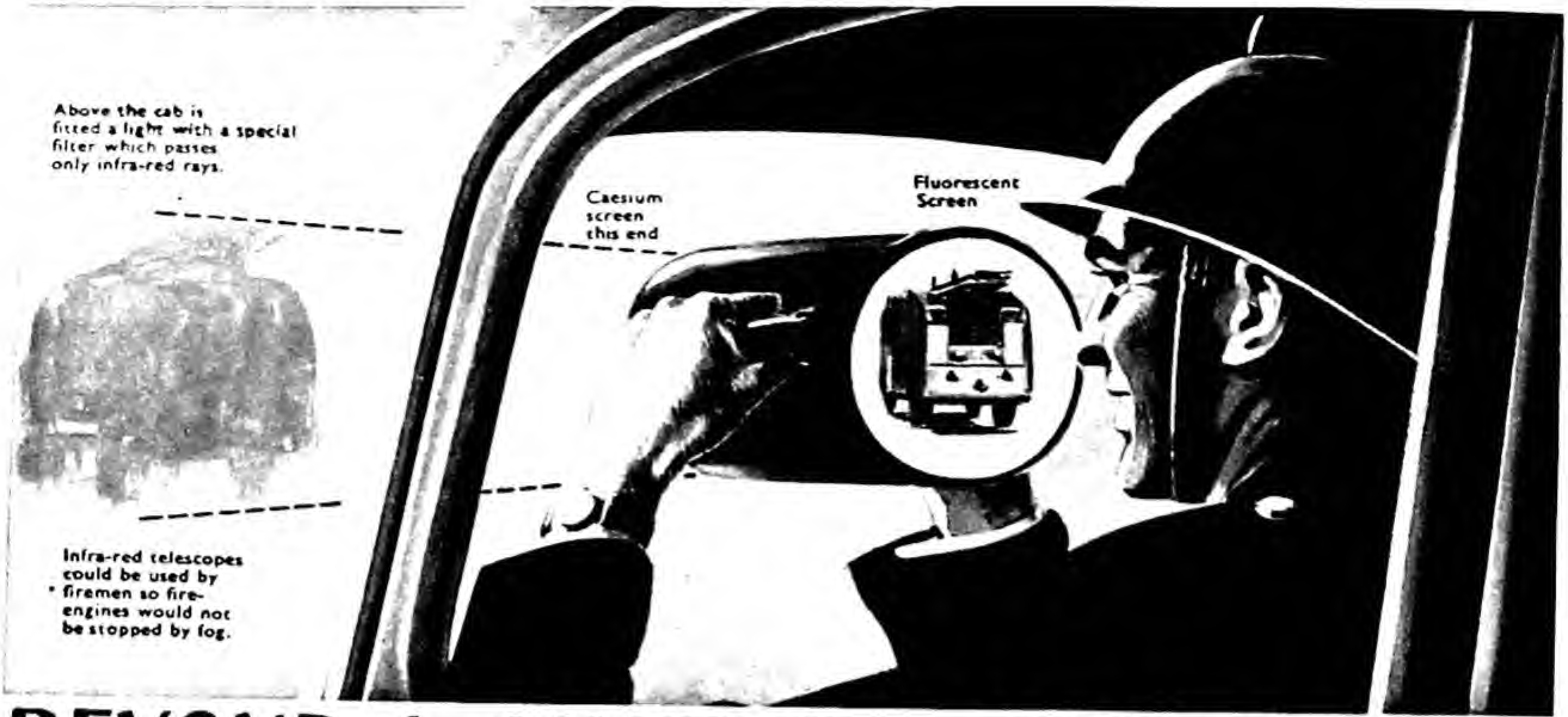
N. American bats migrate north and south searching for the night insects upon which they feed.

Development of SALMON

Salmon swim upriver to spawn then return to the sea. Eels from Europe migrate to the Sargasso Sea to breed.

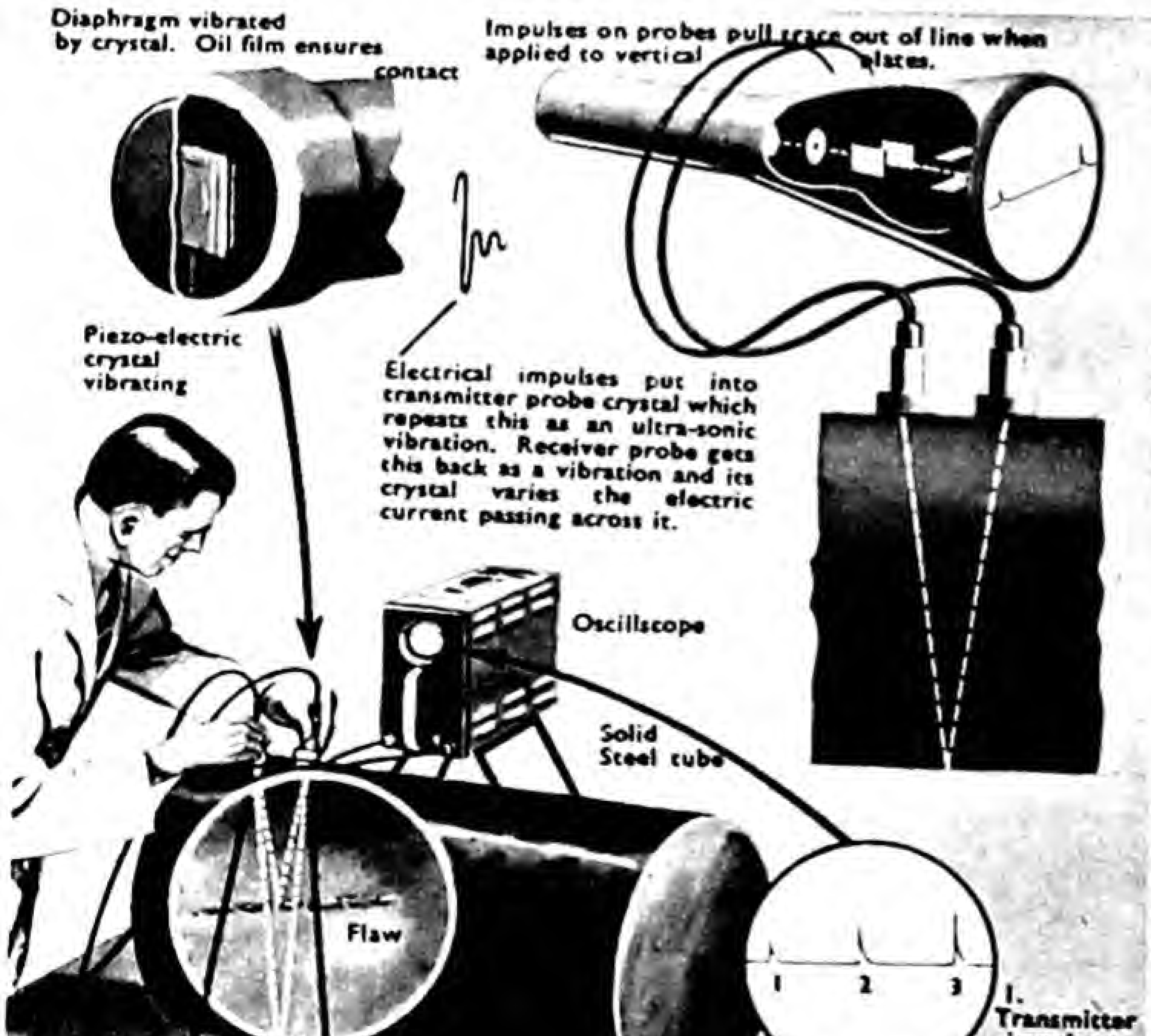


The butterfly leaves Africa and breeds in the Mediterranean, the offspring go on to Europe. Food shortage causes ant migrations, and overcrowding that of locusts.

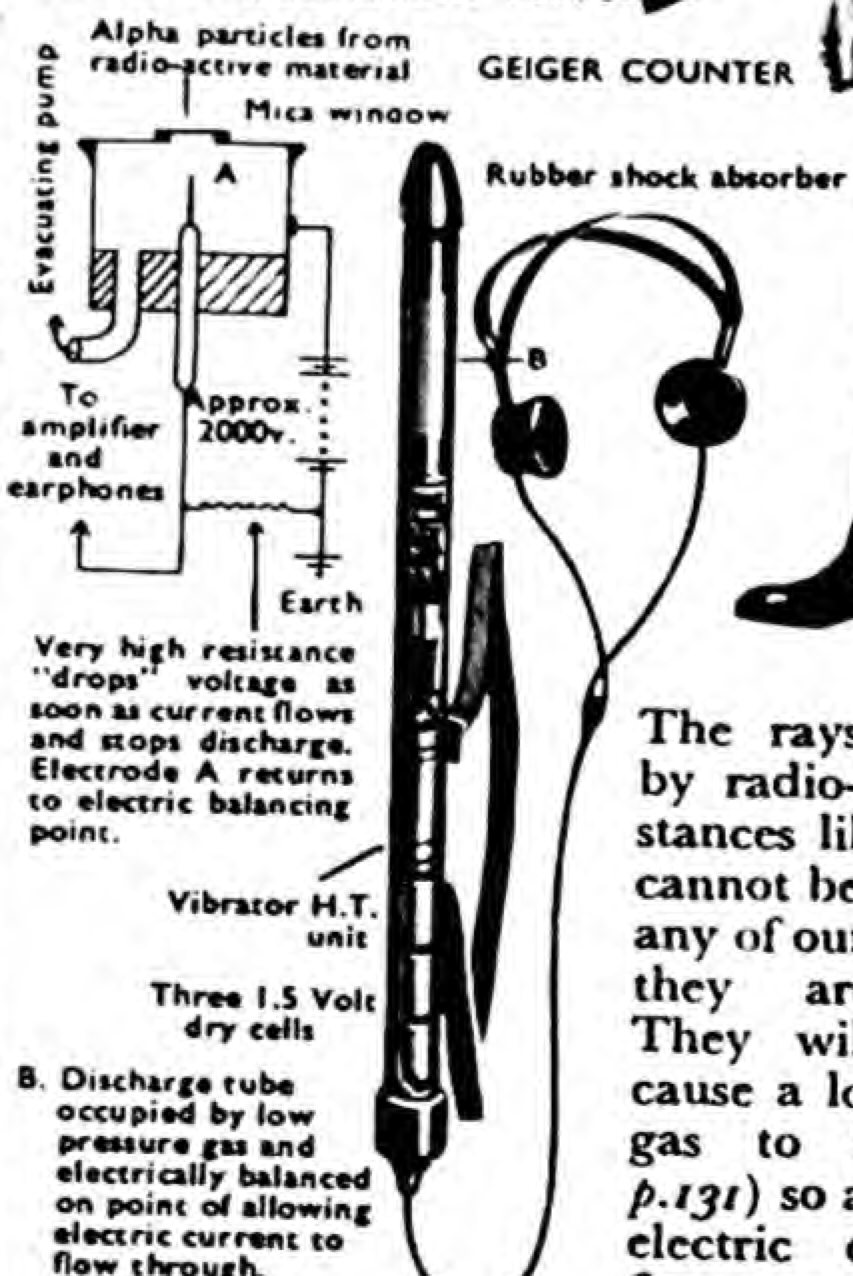


BEYOND the LIMIT of our SENSES

Ultra-sonic vibrations (far faster than the sound waves we can hear) are set up by an electrical oscillating impulse passed across a specially cut crystal. This blip of " sound " travels through anything solid and is reflected back from the far side. Any change of density (a flaw) also reflects the " sound ". The results show up on a cathode ray oscilloscope.



Having longer wave lengths (i.e. frequencies) than light rays, infra-red (or heat) rays are not visible to our eyes. The water droplets of fog do not scatter them so much as light rays, so they produce a clear picture (but invisible to our eyes) on a caesium screen. This gives off electrons (*see p.190*), which strike a fluorescent screen.



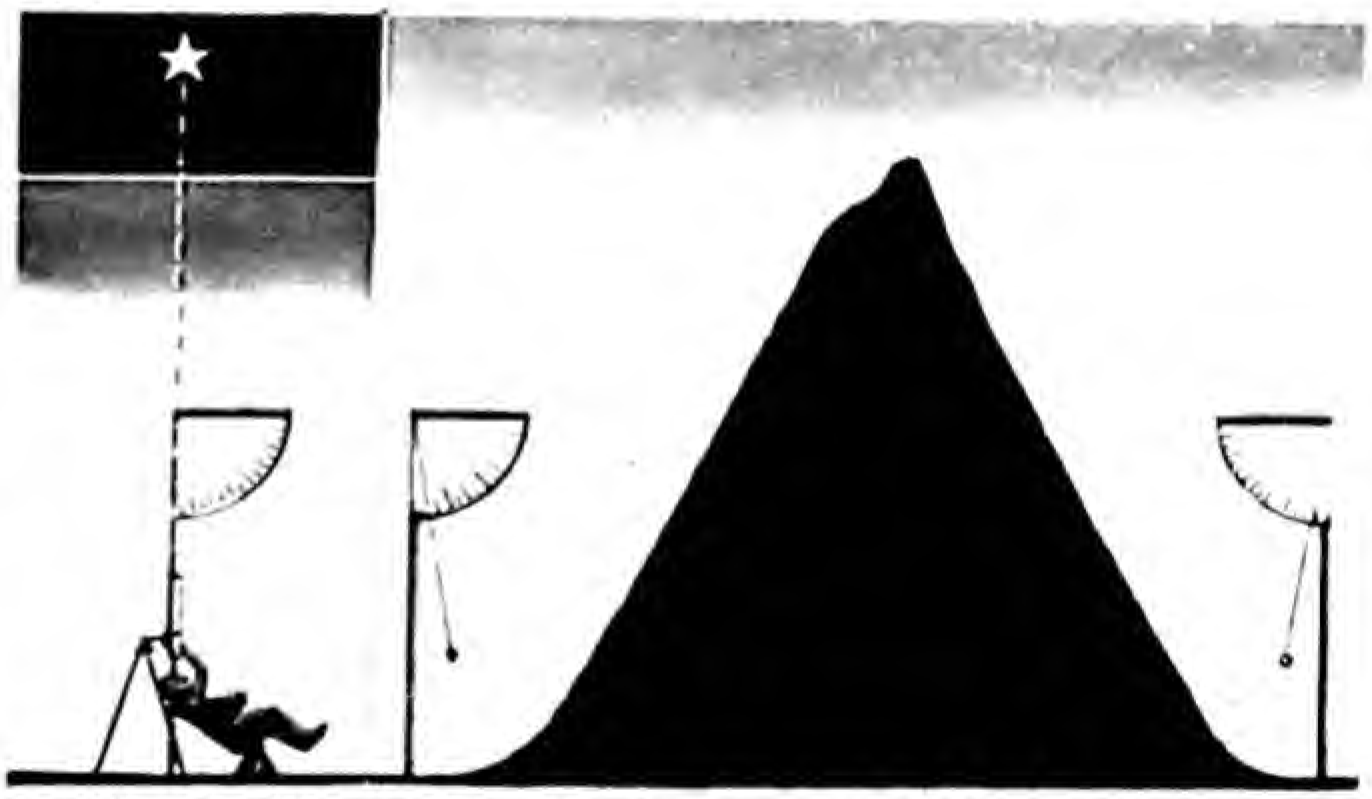
The rays given off by radio-active substances like uranium cannot be noticed by any of our senses, yet they are deadly. They will however cause a low pressure gas to ionize (*see p.131*) so allowing an electric current to flow across. This is amplified in the Geiger Counter to produce an audible signal in the earphones.

THE POWER THAT MAKES THINGS FALL

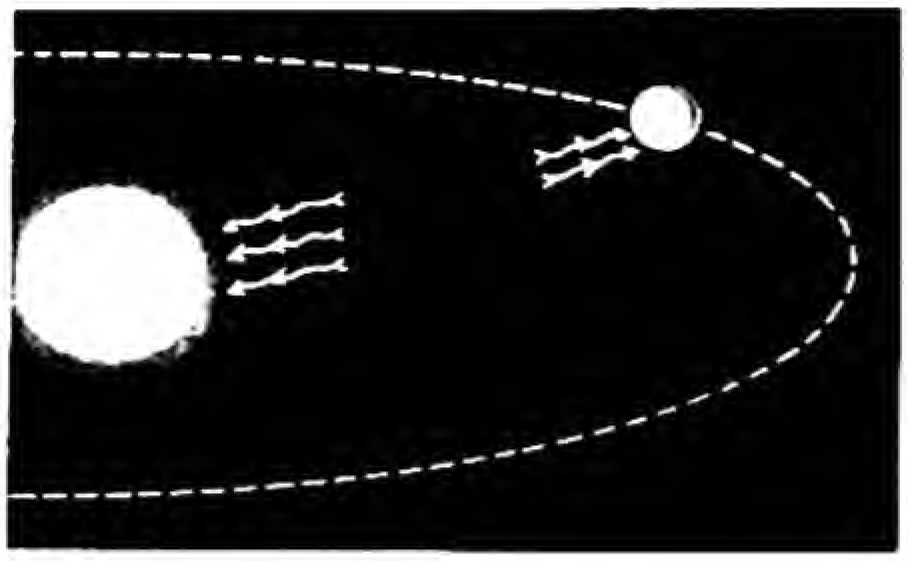
Gravity is the most familiar of all natural forces but it is one that is often misunderstood. A box weighing 10 lbs. will not fall any faster than one weighing 1 lb. *Both* travel *faster* the longer they fall. This is called acceleration. The rate of acceleration is the same for all falling objects. The speed of falling increases by 32 ft. per second every second, as in the imaginary modern version of Galileo's falling bodies experiment on the left. Only when a thing is so bulky compared with its weight that it has to push a great deal of air aside is its speed of fall much slowed down.

Gravity is not a power that belongs to the earth alone. Everything which has mass is

A high speed camera is fixed at each floor of a skyscraper and triggered to take a photo at the end of every second. The cameras that caught the falling objects show how much faster they fall each following second, though both fall at the same speed.

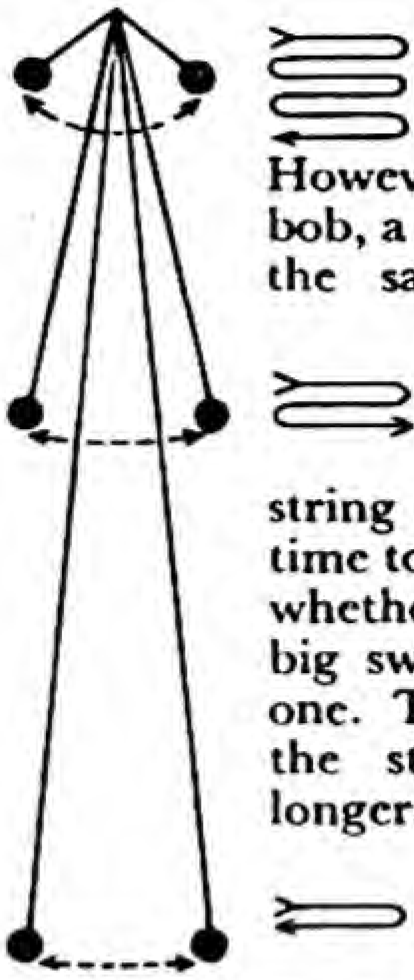


A plumb line normally hangs straight down in the direction of the earth's gravitational pull, but near a large mountain a measurement against a zenith telescope shows the bob has been drawn towards the mountain. The star actually is so far away as to make virtually the same angle when measured from either side of the mountain—the true vertical. The heavier the mountain, the larger the angle that the plumb line makes with this. The mountain's volume of its particular rock must weigh so much, and the Earth's weight is in proportion to the downward pull on the plumb line. By calculating how many times greater the earth's pull is compared with the mountains, the earth is weighed. Because the earth is not exactly a sphere its gravitational pull is not everywhere equal and the rate of acceleration of fall actually varies slightly in different parts of the world. In England it is 32.2 feet per second every second of falling.



The sun, holding the earth in its orbit, is itself pulled by the earth's less powerful gravitational field.

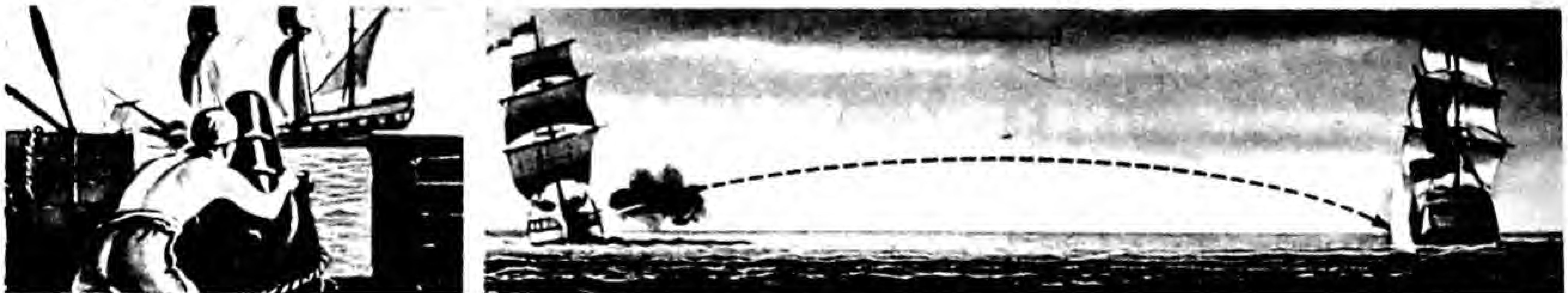
attracted by and attracts other mass. The bigger and more dense the object is, the bigger its gravitational pull on other things. A pendulum returns in its path because of the pull of gravity. Otherwise it would go up and over in a circular course round the point from which it is hung. As it is gravity pulls the bob downwards, but because of its acceleration it overshoots the bottom point of its swing. Gravity then begins to work on it in the opposite direction eventually stopping it and causing it to swing back again and so to and fro.



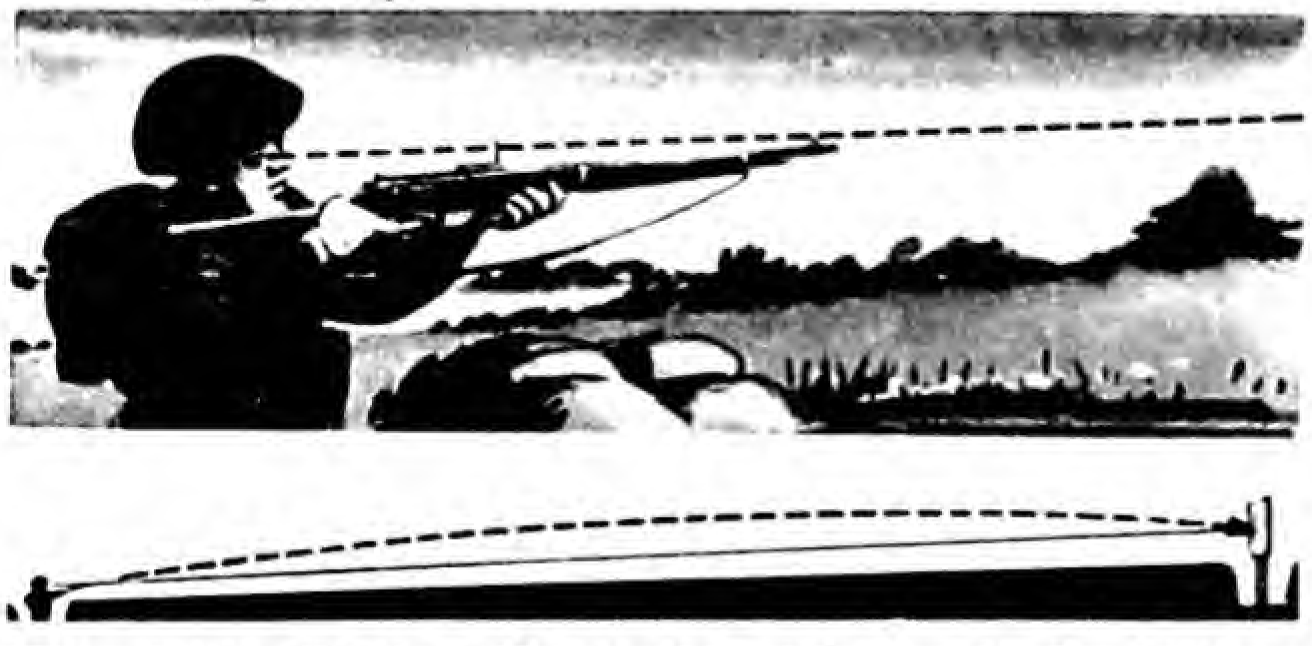
However heavy the bob, a pendulum with the same length of string takes the same time to make one beat whether this beat is a big swing or a small one. To slow the beat the string must be longer.

Pendulums keep clocks ticking evenly because the escapement can only turn after the pendulum has made its sweep and that always takes exactly the same time.


A pendulum swinging freely from the ceiling is found to be tracing out a different line across the floor after several hours, for a pendulum swings on a line in space and the spin of the earth has turned the floor.



In order to hit the water line the gunner aims at the ship's masts, for the cannon ball in flight will be pulled down by gravity.



The sights tilt the rifle at the right angle for hitting the target.

The curved path of a stream of tracer bullets fired up at a bomber.

THE WORK AND LIVES OF FAMOUS SCIENTISTS

ADRIAN, Edgar Douglas, 1st Baron (b. 1889). British physiologist whose researches into the nervous system are of the greatest importance.

AGASSIZ, Louis (1807–1873). Born in Switzerland. Settled in America 1846. Made invaluable contributions to animal classification, especially of fishes and to the study of glaciation.

AMPÈRE, André Marie (1775–1836). French physicist. Ampère rendered great service to science by his experiments which showed that coils of wire carrying electric currents acted in the same manner as magnets of the same size and shape, thus establishing the relationship between electricity and magnetism and laying the basis of a practical electric telegraph.

Ampère revealed his scientific bent early in life. It is said that, as a child, he would amuse himself by working out problems in arithmetic, using stones and crumbs of bread as counters. He suffered two violent emotional shocks in his early life. In 1793 the death of his father, who was executed in the Revolution, left him mentally stunned. In 1799 he married, but the death of his wife a few years later dealt him a second blow from which he never fully recovered.

ANDRÉ MARIE AMPÈRE

APPLETON, Sir Edward Victor, G.B.E., F.R.S., K.C.B., D.Sc. (b. 1892). Eminent physicist who worked under Rutherford at Cambridge.

He was one of the pioneers in the transmission of radio waves and his researches enabled great advances to be made in this branch of science. By his investigations into the behaviour of long-distance radio waves, Appleton obtained new knowledge about the ionosphere. He found that radio waves are caused to bend and pass round the earth by reflecting layers situated at about 150 miles above the surface of the earth.

He was awarded the Nobel Prize for physics in 1947.

ARCHIMEDES (c. 287–212 B.C.). Greek mathematician and inventor, the son of an astronomer, born in Syracuse, in Sicily. The greatest mathematician of ancient times.

Archimedes was the founder of the science of hydrostatics, for which he laid the basis by the discovery of the principle (the Principle of Archimedes) which states that the upthrust on a body immersed in a fluid equals the weight of the fluid displaced by the body.

Although absorbed throughout his life in scientific studies he frequently applied his knowledge to practical matters. He devised for his friend, Hiero, the King of Syracuse, war engines for the defence of his native city. These weapons terrified the attacking Romans and enabled the defenders to hold out for three years.

Archimedes was killed when the city was captured; being run through the body by a Roman soldier while he was drawing a mathematical figure in the sand.

ARRHENIUS, Svante Auguste (1859–1927). Swedish physicist and chemist. After studying at Upsala and a period spent in travelling, he was appointed lecturer in physics at Stockholm in 1891, and professor four years later. Arrhenius's name is specially associated with investigations into the theory of electrolytic dissociation and his paper delivered to the Stockholm Academy of Sciences in 1883 was an historic contribution to the chemical theory of electrolytes. He considered that in watery solution nearly all the molecules of an electrolyte are changed into equal numbers of positively and negatively charged ions.

ASTON, F. W. (1877–1945). British physicist. In 1919 Aston showed by the magnetic analysis of the positive rays of the cathode-ray tube that the element chlorine has two isotopes, one of atomic weight 35, and the other 37. Aston obtained similar results with other elements. Aston's researches added greatly to the existing knowledge of the atomic weights of the atoms of elements and their isotopes. The first model of his mass spectrograph is now in the Science Museum, South Kensington.

AVEBURY, Lord, P.C., F.R.S. (1834–1913). Lord Avebury was an English banker and politician, but he is principally celebrated as a naturalist. His books on natural history and prehistoric archaeology, based on his own keen observations of natural phenomena and animal or plant life, were extremely popular and many of them ran through a great many editions. Among the most widely read were *The Origin and Metamorphoses of Insects*; *British Wild Flowers*; *Ants, Bees and Wasps*; *Prehistoric Times*; and *The Beauties of Nature*.

Lord Avebury, who was better known as Sir John Lubbock, the name he bore until he was raised to the peerage in 1900, was the son of Sir John William Lubbock, also a distinguished man of science. His public honours included honorary degrees awarded him by Oxford, Cambridge and other Universities. He was president of the British Association in 1881 and president of the Linnaean Society 1881–6.

In the famous clash between Bishop Wilberforce and Thomas Huxley at the meeting of the British Association in 1860, when the Bishop, having ridiculed the theory of evolution, was completely routed in argument by Huxley, Avebury (then Sir John Lubbock) put the case for evolution on embryological grounds.

Among his parliamentary activities, Lord Avebury is remembered for his advocacy of proportional representation and his success in securing the statutory observance of Bank Holidays.

ARCHIMEDES

AVOGADRO, Amedeo (1776–1856). Italian physicist who published much material relating to electricity, capillary attraction, atomic volumes, etc. He was a contemporary of Dalton (q.v.), and for many years was professor of higher physics in Turin University. He noted that there was a numerical connection between the combining volumes of gases, and from his observations deduced the rule that is now known by his name—Avogadro's Hypothesis—which states that equal volumes of all gases at standard temperature and pressure contain the same number of molecules. Unfortunately, the theory was not considered to be proved until after his death, a fact which probably impeded progress in chemical research.

BACON, Roger (1214–1294). A Franciscan friar who studied at Oxford and Paris. As an outcome of his wide reading of Arabic and Greek writers, Bacon concluded that the only way to be certain of the truth was to verify beliefs by experiment. He was bold enough to attack established ideas in an age when views such as his were regarded as dangerous heresies. Bacon's own experiments included researches into optics and he appears to have had some knowledge of magnifying glasses and the behaviour of light. But his real contribution to science was the stand he made for scientific methods of reasoning, for which he suffered many years' imprisonment.

BAER, Karl Ernst von (1792–1876). Russian biologist. Discovered the mammalian ovum. Enunciated law of corresponding stages in the development of embryos.

BAEYER, Adolf von (1835–1917). German chemist. Important researches in structure of organic compounds.

BALFOUR, Francis Maitland (1851–1882). English biologist who produced a masterly *Comparative embryology* covering vertebrates and invertebrates.

BANTING, Sir Frederick Grant (1891–1941). Canadian scientist who discovered insulin.

BATESON, William (1861–1926). English biologist who made important studies of the transmission of variation in inherited characters.

BECQUEREL, Antoine Henri (1852–1908). The son and grandson of scientists of distinction, Becquerel, who was born in Paris, succeeded his father at the Musée d'Histoire Naturelle. He did considerable work on magnetism, the polarization of light, phosphorescence and the absorption of light in crystals. His most notable discovery was partly accidental. Some photographic plates left on his desk near a piece of uranium ore were found to be affected as though light had reached them, although they were securely wrapped in a light-tight packet. This led Becquerel to the conclusion that uranium gives out certain rays which can affect a photographic plate after passing through a sheet of paper or metal—the discovery of radio-activity.

He received the Nobel Prize in 1903.

BERTHELOT, Marcellin Pierre Eugène (1827–1907). The son of a doctor, Berthelot distinguished himself at school by his achievements in history and philosophy. Later, turning his attention to science, he rapidly revealed his clear-sighted approach to chemical and medical questions. His reputation was established by the thesis he wrote for his doctorate. He was the first to occupy the chair of organic chemistry at the Collège de France which was instituted especially for him. Berthelot disagreed with the current view held by men of science in his day that there was a division between organic and inorganic chemistry. By synthesising a number of hydro-carbons, fats and sugars he demonstrated that organic compounds could be prepared by ordinary chemical methods without the need for some unknown vital quality. During the siege of Paris in 1870–1871 Berthelot's investigation of explosives enabled him to serve the defenders of the city with technical guidance.

MARCELLIN PIERRE BERTHELOT

BERTHOLLET, Claude Louis (1748–1822). French chemist. After graduating in medicine, he became private physician to the Duke of Orleans. Although his doctrines contained some errors—for example, he believed that the composition of a compound was variable and not fixed—and brought him into disagreement with his contemporaries, his theories and observations regarding chemical affinities contributed greatly to the advance of knowledge of the subject.

BERZELIUS, Jöns Jakob (1779–1848). Swedish chemist. After graduating, Berzelius became a professor of botany and pharmacy. He was elected a member of the Stockholm Academy of Science in 1808. Although he devoted the early part of his career to physiological chemistry, his later interest in the combining proportions of substances led him to the work with which his name is invariably associated. He spent ten years in ascertaining with great accuracy the relative weights of the atoms and molecules of more than 2,000 substances, and it is to him that we owe the system of chemical symbols composed of the initial letters of the Latin (or sometimes Greek) names of the elements and the formulae contrived of letters and numbers to show the grouping of atoms of each element present in a compound. He was the discoverer of the rare elements selenium and thorium and coined the term *catalyst*.

BLACK, Joseph (1728–1799). The discovery of one of the most important properties of matter is due to this careful Scottish experimenter. He studied the change of state of ice to water and from water to steam and found that definite amounts of heat were absorbed with no gain in temperature. He also demonstrated that the same quantities of heat reappear during the reverse changes, freezing and condensation. His discovery of latent heat, besides its more far-reaching consequences, had the immediate result of enabling James Watt to devise the separate condenser—one of his greatest improvements in the design of the steam engine. It was Black who showed that different substances required varying quantities of heat to produce equal changes in temperature, thus originating the important theory of specific heat. His researches established the distinction between heat and temperature which he defined as quantity of heat and intensity of heat.

BLACKETT, Patrick M. S., F.R.S., M.A. (b. 1897). Professor Blackett, one of the outstanding modern nuclear physicists, was awarded the Physics Nobel Prize in 1948 for his work. He revived Rutherford's demonstration of the possibility of one element being transformed into another. Using the cloud chamber perfected by C. T. R. Wilson in 1919, he photographed the paths of particles and confirmed that a nitrogen atom had absorbed an alpha particle, released a proton, and calculations showed that the nitrogen had become transmuted into oxygen. Professor Blackett was appointed to the chair of Physics at the Imperial College of Science in 1953. He published *The Military and Political Consequences of Atomic Structure* in 1948. President of the British Assocation. 1957

BOHR, Niels, Ph.D. (b. 1885). Physicist and atomic research-worker. After passing with distinction his examinations at the University of Copenhagen and obtaining his doctor's degree when only 26 years of age, Niels Bohr studied for several years at the laboratories of J. J. Thomson and Lord Rutherford. When barely 30 years old he was entrusted with the professorship of Theoretic Physics at the University of Copenhagen. He was also appointed director of the Institute of Theoretic Physics, Copenhagen, where numerous Danish and foreign physicists have devoted themselves to the study of atomic science. In 1913, from Rutherford's observations on atomic structure and Planck's quantum theory, he built up the planetary theory associated with his name. In 1922 he received the Nobel Prize. First chairman of the Danish Commission of Nuclear Energy.

NIELS BOHR on his eightieth birthday with the KING AND QUEEN OF DENMARK

BOUSSINGAULT, Jean Baptiste Joseph Dieudonné (1802–1887). Although trained as a chemist, Boussingault's first appointment was as a mining engineer and he went from his birthplace, Paris, to an appointment with an English company in South America. The insurrection in the Spanish colonies caused him to change his employment and he served for a time on the staff of General Bolivar before returning to France. He was appointed Professor of Agricultural and Analytical Chemistry at the Conservatoire des Arts et Métiers, but through his political views was dismissed, though subsequently reinstated when his colleagues threatened to resign. Boussingault made valuable investigations into plant respiration, the function of their leaves, the quantity of gluten in different wheats and the amount of nitrogen in various food substances. He pointed out the important contrast in function between plants and animals—plants absorbing inorganic bodies and building them up into organic substances while in animals the process is roughly the reverse. Boussingault's study of the place of mineral salts in agriculture was important to later research on the use of artificial manures.

BOYLE, Hon. Robert, F.R.S. (1627–1691). English physicist who has been called the father of chemistry. At Eton he was made ill through a wrong prescription made up by an apothecary and this incident is

thought to have determined him to acquire some knowledge of medical drugs. After two years on the Continent with his tutor, he returned to England on the death of his father and from that time he devoted his life to study and research. Boyle and a number of other scientific investigators formed a band of enquirers who met regularly in London and were known as the "Invisible College". Eventually the group became the Royal Society of London and Boyle was a member of the council. His friends later wished him to become President but Boyle, having some objections to the form of oath, declined the honour. Boyle's greatest contribution to chemistry and physics arose from his refusal to take previously accepted theories for granted. He pointed the way to new advances by his doctrine of careful observation and experiment. He found that there were two different kinds of electrical charge which attract each other but repel similar charges. In physiology, his researches were hampered by his innate tender-heartedness which caused him to dislike dissections, particularly those on living animals, although he admitted they could yield valuable results.

Boyle enunciated the law that the volume of a gas varies inversely as the pressure (Boyle's Law).

BRADLEY, James (1693–1791). English astronomer. Discovered aberration of light.

BRAGG, Sir William, O.M., K.B.E., F.R.S., M.A., D.Sc. (1862–1942). Brilliant scientist who employed X-rays to analyse the structure of crystals.

In association with his son, Sir Lawrence Bragg, he devised a method of determining the arrangement of atoms in crystalline substances by what was in effect looking into the interior of the crystals. By his researches in atomic and molecular structure, Bragg was able to explain the difference between such widely dissimilar forms of carbon as the immensely hard diamond and soft, friable graphite. He invented the X-ray spectrometer. He was awarded, jointly with his son the Nobel Physics Prize in 1915.

Sir William Bragg became President of the Royal Society in 1935. He was director of the Royal Institution of Great Britain.

BRAGG, Sir W. Lawrence, O.B.E., M.C., F.R.S. (b. 1890). Distinguished scientist who succeeded Lord Rutherford as Cavendish professor of Experimental Physics at Cambridge University. He was associated with his father, Sir William Bragg, in his work on crystal structure and determined the law governing the reflection of X-rays by the planes of a crystal. During the 1914–18 war Bragg worked as scientific adviser to the Admiralty and carried out acoustical experiments in connection wuth submarine detection.

BRAHE, Tycho (1546–1601). Celebrated Danish astronomer and fellow-worker of Kepler, Brahe was originally a law student, but the occurrence of a total solar eclipse at the predicted time fired his interest in astronomy and he pursued his studies in secret, eventually abandoning his law studies. He noticed the inaccuracy of previous observations of the stars and set about making fresh observations, for which purpose he devised more elaborate instruments.

The King of Denmark, who was impressed with his ability, gave him the island of Hveen where he built and endowed an observatory. Here, for the next twenty years with the utmost painstaking accuracy, Brahe gradually built up the most complete set of observations of the heavenly bodies that had ever existed. He achieved great renown and was visited by eminent persons from all over Europe including James I of England. His latter days were less prosperous. A new Danish monarch deprived him of his pension and he moved to Prague where the Emperor Rudolph II installed him with Kepler and his instruments in a castle. Here illness overtook him and he died a few months later.

BROWN, Robert (1773–1858). English botanist. He described *Brownian movements* of living protoplasm, the result of chance bombardment of colloidal particles by water molecules.

BUFFON, George Louis Leclerc, Conte de (1707–1788). Celebrated French naturalist, the first to put into a complete form an intellectual theory of the evolution of living things. His great *Natural History* in forty-four volumes was published over a period of more than fifty years—Buffon, himself a member of a long-lived family, attaining the age of eighty-one.

CANNIZZARO, Stanislao (1826–1910). Cannizzaro embarked on his university studies with the intention of becoming a doctor, later fought in the Sicilian revolution as an artillery officer and escaped to France on the defeat of the insurgents. He held professorships in Alexandria and Rome where he occupied the chair of chemistry and in 1858 he published an important memoir distinguishing between the atomic and molecular states and explaining the distinction between atomic and molecular weights. He revived Avogadro's Hypothesis (q.v.), first formulated in 1811, and showed how the atomic weights of elements contained in volatile compounds can be ascertained from the molecular weights of the compound. The importance of his achievement was recognized by the award of the Copley Medal of the Royal Society. His name is also associated with a standard method for converting an aldehyde into alcohol and an acid. As a member of the Italian Senate he did much to advance scientific education in his country.

CAVENDISH, Hon. Henry, F.R.S. (1731–1810). An English chemist and physicist who is chiefly famous for his researches into the nature of gases. He discovered hydrogen which he was the first to recognise as a distinct substance. He devised a new eudiometer to determine the composition of the air and he made notable researches in electrolysis, conduction and heat. He supported Newton's view that heat consists of the internal motion of the particles of a body. Among his other notable works were his experiments to determine the density of the earth in which he measured the attraction exercised by large masses of lead on a bar suspended on a wire.

CHADWICK, Sir James, F.R.S. (b. 1891). Brilliant physicist who collaborated in atomic research with Lord Rutherford at the Cavendish laboratory at Cambridge. In 1932 Chadwick, repeating an experiment of Bothe and Becker in which the element beryllium is bombarded with alpha particles, showed that this produced from it a new kind of particle. He realised its character as an essential part of the atom and called it the neutron. In recognition of his outstanding work in atomic physics he was awarded the Nobel Prize in 1935. *Radiations and Radioactive Substances* was written by Chadwick jointly with Lord Rutherford and C. D. Ellis.

CLAUSIUS, Rudolf (1822–1888). German physicist. Evolved first kinetic theory explaining nature of matter.

COCKCROFT, Sir John Douglas, K.C.B., C.B.E., M.A., Ph.D., F.R.S. (b. 1897). Outstanding nuclear physicist who carried out pioneer work with Dr. E. T. S. Walton on the transmutation of atomic nuclei. They were the first to produce an atomic transmutation employing particles artificially accelerated in a machine. They used a system of condensers and rectifiers to secure 700,000 volts with which to accelerate protons.

With Dr. Walton, he was jointly awarded the Nobel Prize for Physics. Director of the Atomic Energy Research Establishment at Harwell.

SIR JOHN COCKCROFT

COPERNICUS, Nicolaus (1473–1543). The celebrated Polish astronomer whose conclusion, reached after almost a lifetime of study of the heavens, that it was the earth that moved round the sun and not the sun round the earth, contradicted the theories of Aristotle and Ptolemy.

Copernicus studied at several Italian universities and qualified as a doctor. Until he was more than thirty years of age he attended university courses in medicine, law, mathematics, astronomy and theology. He became a canon of the church and when he presented his great astronomical work to the Pope, in which he propounded his new theory of the universe, upsetting the orthodox notions of the time, his views were regarded as heresy. He made few astronomical observations—telescopes had not been invented in his day—but reached his conclusion that there must be a better explanation of the movements of the heavenly bodies from careful consideration and study of what was already known about them.

CROOKES, Sir William, O.M., F.R.S. (1832–1919). Celebrated both as a chemist and physicist, Sir William Crookes studied at the Royal College of Chemistry and worked first in meteorology and chemistry.

He became interested in cathode rays while investigating the properties of a new element, the metal thallium, which he had succeeded in isolating by passing an electric discharge through a tube from which practically all the air had been evacuated. His subsequent researches led him in 1887 to conclude that the rays were a new form of matter from which the atoms of the elements were themselves condensed, a theory which became the groundwork of modern electronic physics.

Sir William Crookes was the inventor of the spinthariscope in which the scintillations produced on a fluorescent screen of zinc sulphide by the radiations from a trace of radium are viewed through a lens when the sparks produced by the particles striking the screen can be seen and counted.

He was President of the Royal Society from 1913 to 1916, and in 1898 of the British Association, during his presidential address to which he forecast a world shortage of nitrogen fertilisers. This prediction was falsified only by the subsequent discovery of artificial means of fixing atmospheric nitrogen into compounds suitable for use as plant foods. Crookes himself showed in 1892 that atmospheric nitrogen would unite with oxygen at the high temperature of the electric arc.

In addition to the knighthood conferred on him in 1897, Sir William was honoured by the award of the Royal, Davy and Copley Medals of the Royal Society.

CURIE, Marie (1867–1934) and Professor Pierre (1859–1906). The oppression of the Polish people by the Russian government of the Tsars caused Marie Sklodowska, a gifted young chemist, to escape to France. Although, despite her youth, she had already obtained high academic honours, she found it difficult to obtain employment and she suffered extreme poverty while studying for a degree in Paris. In the course of her work she met Pierre Curie, a French scientist, who was engaged in experimental work in physics. Becoming friends through the common interest of their work, the two scientists married. Thus was formed one of the historic and fruitful partnerships of science, broken unfortunately eleven years later by the tragic death in 1906 of Pierre Curie in a street accident.

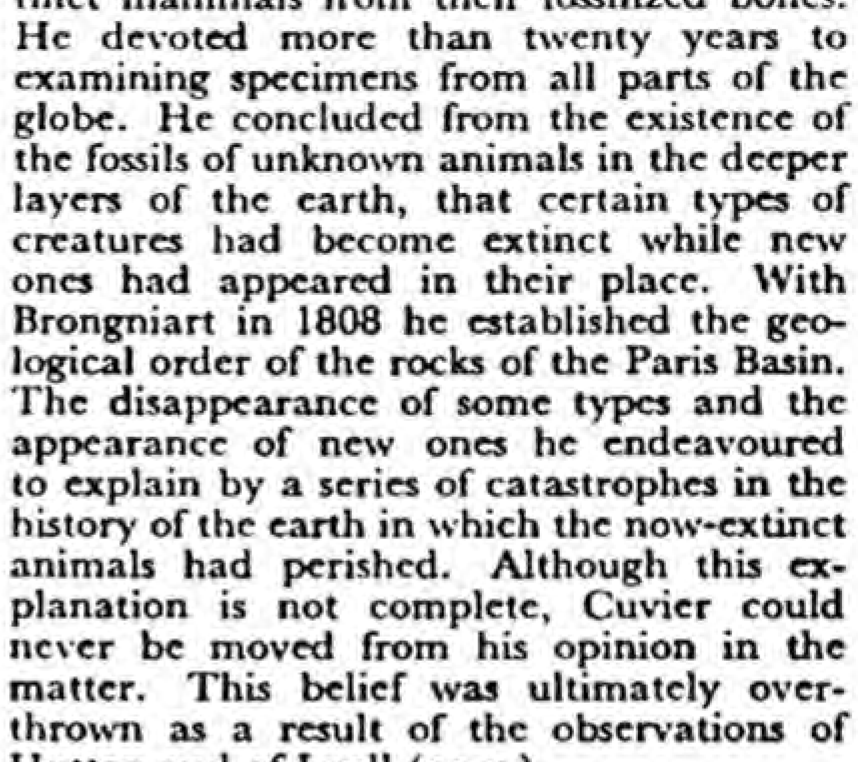
Because both were extremely poor, the Curies carried out their experimental work in makeshift laboratories in damp underground rooms and in leaking shanties, but obtained results which were to transform the worlds of science and medicine.

They examined a mineral called pitchblende and obtained from it a radioactive element which Madame Curie named polonium in honour of her mother-country. After more years of patient labour she obtained a tiny specimen of radium and assigned it to its right place among the elements. Radium has been the starting point of many researches into the structure of the atom. It has also been extensively used in the treatment of cancer and other diseases, and through the work of the Curies a vast amount of human suffering has been alleviated.

The Curies received many honours in recognition of their great pioneer work. Madame Curie was twice awarded the Nobel Prize; jointly with her husband in 1903 and again in 1911.

CUVIER, Georges (1769–1832). Celebrated French naturalist, whose work founded the science of comparative anatomy. He was in charge of the Jardin des Plantes in Paris and while there he was shown some fossils dug up by workmen who were making excavations. From his knowledge of anatomy, he saw that a number of the fossils evidently did not belong to any creature then known and he realised that the earth had once supported many kinds of animals quite unlike those of the present time. Cuvier became intensely interested in the study of fossils and reconstructed many extinct mammals from their fossilized bones. He devoted more than twenty years to examining specimens from all parts of the globe. He concluded from the existence of the fossils of unknown animals in the deeper layers of the earth, that certain types of creatures had become extinct while new ones had appeared in their place. With Brongniart in 1808 he established the geological order of the rocks of the Paris Basin. The disappearance of some types and the appearance of new ones he endeavoured to explain by a series of catastrophes in the history of the earth in which the now-extinct animals had perished. Although this explanation is not complete, Cuvier could never be moved from his opinion in the matter. This belief was ultimately overthrown as a result of the observations of Hutton and of Lyell (qq.v.).

One of Cuvier's most valuable contributions to science was the system of zoological classification which he compiled, in which he divided all animals into four main groups: (1) The vertebrates (animals with a backbone; (2) Molluscs (shellfish, etc.); (3) Articulated or jointed animals, such as lobsters, spiders and insects; (4) The radiated type—a mixed group including starfish, etc.



GEORGES CUVIER

DALTON, John (1766–1844). Famous chemist and mathematician, born in Cumberland of Quaker parentage. He became a schoolmaster in Manchester, teaching mathematics and physics. In 1810 he published his *New System of Chemical Philosophy*, in which his celebrated Atomic Theory was explained. Although the possibility of an atomic structure of matter was, as an idea, not new and had been familiar to the Greeks, Dalton's great service to chemical science was that he presented his theory in such a way that it was convincing. This was because its conclusions were based on experiments which revealed a constancy of proportion in the combining weights (equivalents) involved in chemical reactions. These experiments could be repeated and extended as proof of the soundness of the Atomic Theory.

DARWIN, Charles Robert (1809–1882). Darwin was born at Shrewsbury, the son of a successful physician and the grandson of Erasmus Darwin. He first studied medicine at Edinburgh and then with the idea of entering the church, went to Cambridge to prepare for holy orders. Darwin had shown no enthusiasm for any career, but at Cambridge, the famous botanist, John Henslow, aroused his interest in botany and secured him an unpaid post as naturalist on the naval survey ship *Beagle* on her voyage in the Southern Seas. This resulted in Darwin's discovering his true vocation as a scientific investigator. He was away for five years, sailing round South America, visiting the volcanic Galapagos Islands and then crossing the Pacific to Australia. From his investigations of plant and animal life made on the voyage, Darwin became a believer in the idea of evolution. He outlined his theory in 1884, by which time Wallace (q.v.) had come to similar conclusions.

It was some years before he had thoroughly sifted the results of his observations and in 1859 published his great work the *Origin of Species*, considered by many one of the great books in history.

Darwin's theory was violently attacked because at first his arguments were not understood. Some people thought, quite wrongly, that Darwin was claiming that man was descended from apes and others imagined he was attacking religion. When people saw Darwin's views more clearly, the opposition diminished. His evidence for the reality of evolution still stands to this day but his ideas concerning the manner of its happening have largely been superseded as a result of the newer knowledge of heredity.

In 1871 appeared Darwin's *Descent of Man*, and his other works include *Emotion in Man and Animals*, *Different Forms of Flowers* and *Insectivorous Plants*.

DAVY, Sir Humphry (1778–1829). Born at Penzance in Cornwall, Davy was apprenticed at 16 to a surgeon and apothecary in Penzance. He was a keen student, a voracious reader and an industrious writer. The publication of some of his scientific essays secured him an appointment to the Pneumatic Institution at Bristol, where the effectiveness of new gases for medical purposes was being tested. Here Davy found that with proper precautions nitrous oxide (laughing gas) could be used, as it is at the present time by dentists, as an anaesthetic. To effect this discovery, Davy made tests of the gas on himself at considerable risk to his own life. Davy's next move was to London, where he was appointed by the Royal Institution to the joint offices of assistant lecturer in chemistry, director of the laboratory and assistant editor of the Institution's journals at a salary of one hundred guineas a year. Because of his

remarkable gift for speaking, his lectures were extremely popular and well attended.

In the course of his connection with the Royal Institution which he maintained throughout the rest of his life, Davy made a number of important discoveries regarding the properties of metals. He discovered sodium, potassium, magnesium and other alkali metals; by the electrolysis of caustic alkalis proved chlorine to be an element.

Following his return from an extensive continental tour with his young laboratory assistant, Michael Faraday, Davy investigated the cause of the frequent grave mine explosions which were then occurring. The outcome was his most celebrated achievement, the invention of the miner's safety lamp. Davy did not patent this invention and thereby reaped no financial reward, which was doubtless his intention.

Davy received numerous honours in recognition of his services to science. He was given a knighthood in 1812 and later was made a baronet. He was elected President of the Royal Society a few years before he died.

PAUL EHRLICH

DEMOCRITUS (460–361 B.C.). Greek philosopher and physicist. First stated law of conservation of matter.

DEWAR, Professor Sir James, F.R.S. (1842–1923). Leading Scottish chemist who carried out some important experiments with gases. In 1898 he obtained liquid oxygen. He succeeded in liquefying hydrogen for the first time in 1898 and later was able to reduce it to solid form as a transparent substance.

Dewar used double-walled flasks from which the air had been exhausted so that no heat was conducted and evaporation of the liquid was prevented. Silvering of the walls increased their effectiveness. This device was the origin of the Dewar or vacuum flask now universally used as a container for hot or cold drinks.

Dewar was appointed Fullerian Professor of Chemistry at the Royal Institution in 1877 where, in the laboratories, he carried out most of his experimental work. He often attributed his manipulative skill to an illness in his boyhood following a fall through the ice of a frozen pond, when, during his convalescence at home, he was taught the use of tools by the village joiner.

EDDINGTON, Prof. Sir Arthur Stanley, O.M., F.R.S. (1882–1944). Famous astronomer and director of the Cambridge Observatory and Plumian Professor of Astronomy, Cambridge. He devoted himself to the study of astrophysics to which science he made notable contributions. He wrote many books of which *The Nature of the Physical World* and *Stars and Atoms* are among the best known.

EINSTEIN, Professor Albert (1879–1955). World famous scientist whose *General Theory of Relativity* caused scientists to revise their most fundamental ideas of gravitation. Einstein revised or supplemented Newton's laws in their application to very small bodies like atoms or very large ones like galaxies. He showed that space and time were in reality inseparable and that time constituted a fourth dimension. He was awarded the Nobel Prize for Physics in 1921.

Einstein was director of the Kaiser Wilhelm Physical Institute in Berlin but was exiled by the Nazis and thereafter carried on his researches at Princeton University in America.

EHRLICH, Paul (1854–1915). German bacteriologist whose discoveries paved the way to the founding of the modern science of chemotherapy or the treatment of infectious diseases by chemical means. He produced dyes which were selectively absorbed by parasitic microbes. These he sought to make poisonous to the microbes. One of his most notable discoveries was an arsenical compound known as salvarsan which destroys the micro-organism *Spirochaete Pallida*, which causes syphilis.

Ehrlich was director of the Institute for Experimental Therapeutics at Frankfort-on-Main where he carried out important laboratory work in cancer research.

FABRE, Jean Henri (1823–1915). French naturalist who wrote many books based on his observations of insect life.

FARADAY, Michael, F.R.S. (1791–1867). Famous chemist and experimenter whose researches laid the basis of electro-chemistry and of modern atomic and electronic science. Faraday, the son of a blacksmith, as a youth was employed by a bookbinder, and his scientific interest was stimulated by studying the books that he delivered to his master's customers. He wrote a report of a lecture delivered by Sir Humphry Davy at the Royal Institution and when this was seen by Davy, he appointed Faraday his assistant at a salary of 25*s.* per week.

Faraday's brilliance was soon recognised and he later became lecturer and then director of the laboratory. After Davy's death, Faraday succeeded him as Professor of Chemistry at the Royal Institution.

Among Faraday's successes was the liquefaction of chlorine, but his greatest achievements were in the realm of electricity and magnetism; his discovery of electro-magnetic induction, which is the principle of the dynamo, being the most important.

FISCHER, Emil (1852–1919). Celebrated German chemist whose work in organic chemistry and in particular the chemistry of proteins laid a sure foundation for modern research on the subject. Fischer showed that proteins are composed of groupings of numbers of molecules of substances called amino-acids. Fischer also carried out extensive research on dyes and sugars.

He was awarded the Nobel Prize for chemistry in 1902.

ALBERT EINSTEIN

FLAMSTEED, John (1646–1719). First English Astronomer Royal. A friend of Newton whom he supplied with astronomical data. Catalogued the stars and checked the tables of their motions to assist navigation. He improved on earlier measurements of the speed of sound.

FLEMING, Sir Alexander, F.R.S. (1881–1955). Professor of bacteriology at St. Mary's Hospital in London. When a culture of staphylococci was accidentally contaminated by a mould, he noticed that the bacteria near the mould died. The mould was a species of Penicillium from which in 1939 penicillin was later prepared. It was not until the war, when problems of manufacturing the drug in large quantities were overcome, that its great value was fully recognised and by its use many diseases were treated successfully and many amputations avoided.

Fleming was awarded the Nobel Prize for medicine jointly with Sir Howard Florey and Dr. E. B. Chain in 1945.

FLEMMING, Walther (1843–1915). German biologist and pioneer of the science of cytology (the study of cells).

FLOREY, Sir Howard (b. 1892). Separated the drug now used medicinally from the original crude penicillin preparation.

FRANKLIN, Benjamin, F.R.S. (1706–1790). Famous American statesman and philosopher. In his early years Franklin, who was born in poor circumstances, worked as a printer in Philadelphia and London. By hard work Franklin progressed from printer to publisher and then to newspaper proprietor and on his retirement devoted himself to scientific research. His assertion that lightning was a form of electricity was ridiculed at first but in a great thunderstorm in Philadelphia he collected the lightning's electric charge by means of a kite fitted with a metal point. The electrical discharge travelled down the wet twine and was collected in leyden jars. Franklin's discoveries eventually received recognition. The Royal Society elected him a Fellow and he was awarded degrees by Oxford and Edinburgh Universities.

In his lifetime Franklin carried out important political missions to England on behalf of his country and took part in the framing of the declaration of American Independence.

FRAUNHOFER, Joseph (1782–1826). Though he started life as a poor orphan boy apprenticed to a mirror-maker, the results of the researches made by Fraunhofer into the spectra of the sun and the reflected light of the moon and planets proved of very great importance.

While he was an apprentice, the house in which he was working collapsed and Fraunhofer was buried in the ruins. The Prince of Bavaria, who witnessed his escape, gave him a large money present. The young man used it to set up for himself. A few years later he became the head of an important optical works and his improvements in the manufacture of glass, which resulted in more accurate scientific instruments, made his works famous.

With a prism made of his improved glass, he was able to observe in the sun's spectrum a number of dark lines crossing it at intervals and similar dark lines in the spectra of the planets. In repeated observations, he found that the lines were always in the same place though the lines in the light coming from certain fixed stars were differently grouped. He made careful records of all the lines which have become known as Fraunhofer's lines.

JOSEPH FRAUNHOFER

GALEN (or Galenus), Claudius (130–200). Famous physician, and the most notable of ancient medical writers. His writings are numerous and cover a wide variety of topics. He was born in Pergamus, in Mysia, and after studying in Smyrna, returned to his native city. Eventually he went to Rome and became physician to the Emperors Marcus Aurelius and Lucius Verus. Galen practised as a physician in Rome for some years and his extraordinary success in healing earned him the title of the wonder-worker and also incurred the envy of his fellow physicians. He dissected animals in his unsuccessful search for the nature of life but laid the foundations of anatomy by his observations. Many of Galen's writings are still in existence. For many centuries Galen's medical treatises were accepted as authoritative.

GALILEO, Galilei (1564–1642). Great Italian mathematician and astronomer whose long life was one of phenomenal intellectual activity. Some of his ideas directly contradicted the accepted beliefs of his day and a number of them caused a complete revision of the beliefs then held by scientists. Many of his experiments on falling bodies were conducted from the leaning tower in his birthplace, Pisa. He constructed the first astronomical telescope, discovered the importance of acceleration, and propounded the law of falling bodies. He proved that the sun is the centre of the planetary system and that the earth revolves round it and not the contrary. His theories were thought to contravene the teachings of the Church, and for maintaining them he was tried for heresy by the Inquisition.

GALVANI, Luigi (1737–1798). Italian physician and physiologist. His famous discoveries in animal electricity which has been called galvanism after him, followed experiments he made on the muscles of frogs. The most celebrated of his experiments was carried out by suspending a frog's legs by copper hooks on an iron railing which produced twitching of the leg muscles. This led Galvani to the invention of his metallic arc. The arc was made of two different metals, one of which was placed in contact with the frog's nerve and the other with a muscle, which caused the muscle to contract. Galvani concluded that electricity was being produced by the frog's legs and the two different metals. He was wrong about this but his experiment paved the way for a later investigator, Alessandro Volta, to arrive at the true explanation—namely that electricity was generated by the conjunction of the two different metals; the nerve and muscles in Galvani's experiment were merely responding to the electric shock.

GALTON, Francis (1822–1903). Made statistical studies of human heredity. Believed man could be improved by selective breeding which he called *Eugenics*.

GAUSS, K. F. (1777–1855). German mathematician who made very great contributions to several branches of mathematics by his researches and immensely laborious calculations.

In 1834 he instituted at Göttingen the first special observatory for terrestrial magnetism. From this observatory he sent telegraphic signals to a near-by town, thereby demonstrating the possibility of an electromagnetic telegraph.

He formed an association to carry out magnetic observations; the members recording the results of their observations at points extending from the Netherlands to Sicily. Some of the improvements in instruments and methods he instituted form prototypes of the best practice in later magnetic observations.

GAY-LUSSAC, Joseph Louis (1778–1850). French chemist who early in his career assisted C. L. Berthollet in his researches. Gay-Lussac's independence of mind soon revealed itself when he unhesitatingly pointed out what he considered to be discrepancies in the results of the experiments set him by his master. The older man was not offended by his outspokenness but, realising his assistant's scientific integrity, did all he could to further the young man's progress.

Gay-Lussac became in turn professor of physics at the Sorbonne and at the Jardin des Plantes. His earlier researches were mainly concerned with the properties of gases, vapours, hygrometry and capillarity. Of great scientific importance was his demonstration that gases always combine in volumes that bear simple ratios to each other, which with Dalton's atomic theory made it clear that equal volumes of all gases must contain numbers of atoms having simple ratios to each other.

Gay-Lussac made improvements in methods of analysis and as a technical advisor to industry he brought many advances to methods of chemical manufacture. He was bold and fearless, making unaccompanied balloon ascents to study atmospheric conditions and magnetism and remaining at heights of 23,000 feet in temperatures below freezing-point to make his observations. Once, during the eruption of 1805, he visited Vesuvius and approached close to the smoking crater to study volcanic phenomena.

LUIGI GALVANI

GEBER (c. 850). An Arabian alchemist who is believed to have lived about the ninth century. A great many collected writings on alchemy have been attributed to him, though some authorities question the authenticity of many of them. Despite the absurdities of some of the early alchemists, much of the work of Geber was true experimental research, yielding practical results. In the writings believed to be his, he describes practical methods for evaporation, filtration, distillation, sublimation, melting and crystallisation. He describes the preparation of *Aqua fortis* or nitric acid, from saltpetre, alum and copper sulphate and he certainly knew how to prepare other strong acids and numerous chemical substances.

The chemical names used by Geber and some others are still used; for example, *alkali*, *alcohol*, *borax*, *natron*, *talc*, *tartar*.

GIBBS, J. Willard (1839–1903). Celebrated American physicist. Applied thermodynamic methods to chemical problems.

GILBERT, William (1540–1603). Distinguished Elizabethan scientist and author of the first great work on magnetism and electricity.

Gilbert was educated at Colchester School and at Cambridge and after graduating went into practice as a physician. He

was admitted to the College of Physicians, later becoming its treasurer. In 1599 he became physician to Queen Elizabeth and he continued to be court physician under James I until his death.

During the reign of Elizabeth, he enjoyed a pension which was given him to carry out his researches. In his treatise on magnetism, Gilbert dismisses the ideas then held of its magical properties as nonsense. He describes experiments which prove that a magnet has two poles, one seeking the north and the other the south. He demonstrated that if the magnet is cut in two, it becomes two magnets, each with two poles and he showed that like poles repel each other.

Gilbert has been called the "Father of Electricity and Magnetism". He pointed out that the earth itself is the great magnet that attracts the compass needle.

He investigated the forces which develop when friction is applied to certain substances such as amber, and he coined the name electricity from a Greek word meaning amber. He was the first to discover that many other substances could be electrified by friction.

Gilbert's researches on magnetism were of great benefit to mariners; increased knowledge of its properties enabling them to make better use of this important aid to navigation.

GRAHAM, Thomas (1805–1869). British chemist born at Glasgow. He was originally intended for the ministry, but in his student days his interest in experimental science made him decide to adopt it as his career. After graduating, he taught mathematics and chemistry, became professor of chemistry at the Andersonian Institute and later occupied the chair of chemistry in University College, London. Most of his scientific work was done before 1855 when he resigned the chair to become Master of the Royal Mint.

Graham obtained important results by methods which his fellow scientists regarded as strikingly simple. He made some important observations of the diffusion of gases, developing the law to which his name has been given, which states that the diffusion rate of gases varies inversely as the square root of their density. From these investigations he was led to examine the spontaneous movements of liquids, from which he drew the conclusion that soluble substances could be divided into two great classes —*Colloids* and *Crystalloids*. This classification became very important in the later study of the chemistry of proteins.

GUERICKE, Otto von (1602–1686). German physicist. Originally trained for the law, von Guericke studied mathematics and mechanics and became an engineer. He was interested in scientific experimentation and carried out many attempts to create a vacuum. To do this, he first tried to pump the water out of a full barrel but the attempt failed because as the water was expelled the air entered in its place through cracks between the staves and the minute spaces in the wood. His next attempt with a copper globe was more successful and in devising a method of evacuating the air from this container he became the inventor of the first air-pump.

The experiment for which he is best remembered is his famous demonstration with the Magdeburg hemispheres. He had made two hemispheres of copper 14 inches in diameter, the edges of which fitted exactly. When he had exhausted the air from them by means of his air pump, two teams each of fifteen powerful horses harnessed to the hemispheres were unable to pull them apart. The experiment demonstrated the tremendous pressure of the atmosphere. Von Guericke also invented the first friction machine for generating electricity. This simple device consisted of a ball of sulphur which could be rotated while a suitable substance was held lightly against it. In 1672 he showed that in a vacuum clocks make no sound and fruit remains unspoiled for six months.

HAECKEL, Ernst Heinrich (1834–1919). German biologist, born at Potsdam. Though he graduated in Berlin in medicine and surgery, his greatest interest was natural history, and he resigned his practice and subsequently a professorship in anatomy at Jena University to take the specially-established chair of zoology. Haeckel's industry was enormous and his literary output included more than forty scientific works apart from numerous treatises.

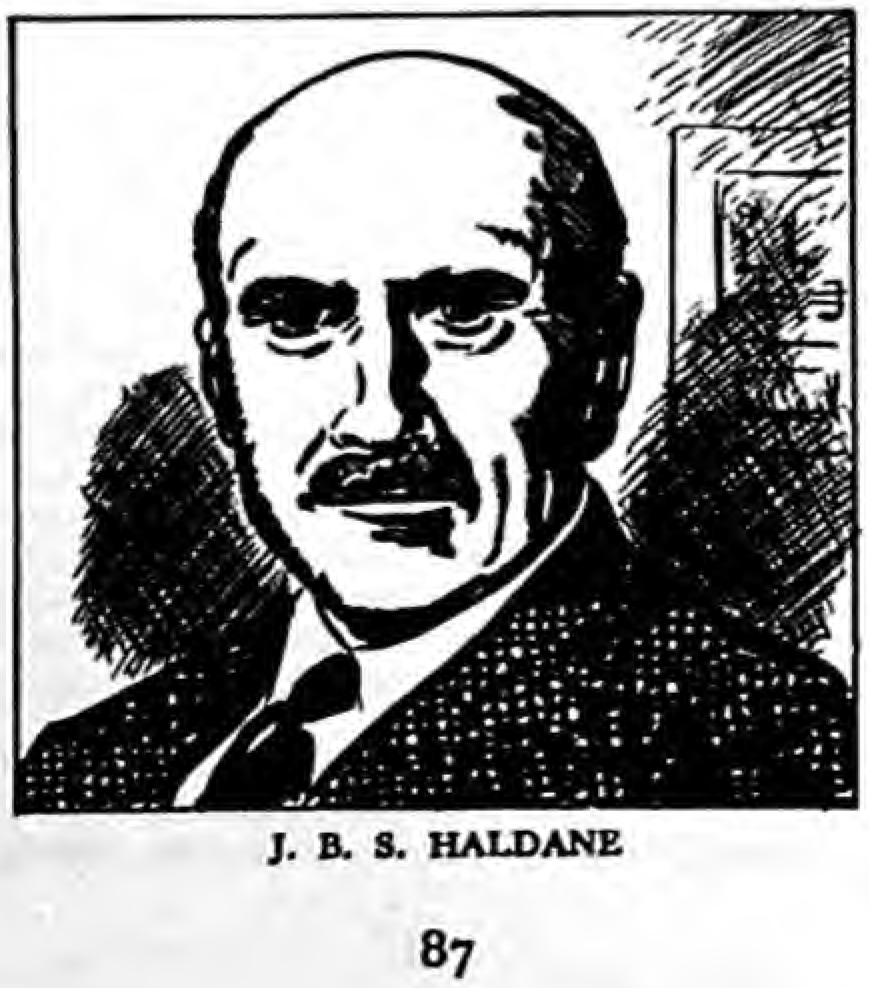
Early in Haeckel's scientific career Darwin's *Origin of Species* was published, and when it came into his hands he readily accepted Darwin's theory and became a stout protagonist of Darwinism in Germany. He was the first German scientist to give whole-hearted support to the theory of evolution and he produced several biological works of great importance developing Darwin's ideas. His writings on sponges, jelly-fish and corals, which enumerated more than four thousand new species, are accompanied by numerous plates.

Haeckel made the first attempt to draw a genealogical tree of animal life showing the relationship between the various orders of animals. He wrote extensively on heredity, various problems of embryology and allied subjects.

Among his best-known works are *The Natural History of Creation*, and *The Evolution of Man*.

HALDANE, Professor John Burdon Sanderson, F.R.S. (b. 1892). One of the most outstanding of modern biologists.

Haldane was educated at Eton and Oxford and during the Great War served in the Black Watch in France and Iraq. He was Fullerian Professor of Physiology at the Royal Institution and later Professor of Genetics, and then Professor of Biometry at University College, London.



J. B. S. HALDANE

Haldane has written extensively on mathematical and biological subjects for learned journals and has also been responsible for many popular treatises and broadcasts by which he has helped to make scientific subjects intelligible to the ordinary reader.

Haldane's numerous published works include *Animal Biology* with J. S. Huxley, *Science and Ethics*, *Enzymes*, *The Causes of Evolution*, *Science and Everyday Life* and *New Paths in Genetics*.

HALLEY, Edmund (1656–1742). English astronomer. Calculated the orbit of the 1682 comet and correctly predicted its return in 1759.

HARDY, Sir William (b. 1864). English physiologist. Gave the name *hormones* to certain internal secretions which act as chemical messengers.

HARVEY, William (1578–1657). Harvey was educated at King's School, Canterbury, and at Caius College, Cambridge. He afterwards went to Padua, where he studied anatomy under Fabricius, and on his return to England he lectured at the Royal College of Physicians in London. In 1618 he was appointed physician to the king. Harvey's interest in the circulation of the blood had started at Padua, where, with Fabricius, he studied the valves in the veins. He now applied himself to finding the connection between the veins and the arteries by experiments on more than forty species, including worms, insects, crustacea and fish. He found that the amount of blood passing in half an hour from the left side of the heart through the arteries was more than the total amount in the whole body. This led him to the conclusion that the blood was going round the body and returning to the heart and was not, as Galen and his other predecessors had supposed, pulsing backwards and forwards in both arteries and veins to and from the heart. Harvey proved the truth of his theory by numerous experiments but it was so completely opposed to the accepted views that it was at first received with incredulity.

Before his death in his eightieth year Harvey's circulation theory had been generally accepted by the highest medical authorities.

HARRISON, Ross (1870). American physiologist. Evolved method of culturing living animal tissue outside the body to study cell growth.

HEISENBERG, Werner (b. 1901). At Munich University, in 1925, this brilliant German theoretical physicist framed a new theory of quantum mechanics. His system explained the structure of the atom by means of a formula based on the frequencies and intensities of spectrum lines which could be observed and measured. Heisenberg opposed the conception of planetary electrons of Rutherford and Bohr and declared that Newtonian astronomy did not belong to atomic physics. He demonstrated that it was not possible to specify with complete accuracy at the same moment

both the position and the velocity (or momentum) of a particular atomic particle.

Eddington called this new theory, which revolutionised physical science, the principle of uncertainty. Its elucidation has greatly assisted the work of other physicists.

For his contribution to atomic physics Heisenberg was awarded the Nobel Prize.

HERO OF ALEXANDRIA (c. A.D. 100). Greek geometrician and author of numerous tracts on mechanics and physics, some of which survive in fragmentary form. Hero made some important observations in optics and on the behaviour of light, demonstrating that when light is reflected from a surface it is at an angle equal to the angle of incidence. He also advanced a number of geometrical theorems. His writings on mechanics reveal that he understood the working of cogwheels, pulleys, the rack and pinion and the principle of leverage. He designed many ingenious mechanical contrivances which in his day had no other value than as entertaining conjuring tricks. The most celebrated of his toys, the aeolipile, was a metal globe containing water and mounted on a pivot. When the water was heated and converted into vapour, the steam escaped from the sphere through pipes facing in opposite directions, the reaction from the escaping steam causing the globe to rotate. This device was used for turning spits for roasting meats and working the bellows of organs. Centuries later the same principle was put to more important uses in the shape of the powerful and efficient steam turbine.

HERSCHEL, Sir John Frederick (1792–1871). English astronomer. Suggested use of spectral lines for the identification of metal elements. Invented an actinometer to measure heating effect of solar rays.

HOOKE, Robert (1635–1703). One of the most brilliant experimenters in microscopy, the study of biology owes a good deal to the work of Robert Hooke. Through his observations, the smallest unit of living matter, the cell, was discovered. He observed that the tissues of a plant were not continuous but were made up of numerous minute chambers which he called cells, and the word has been adopted and used by biologists ever since. Hooke's famous work, *Micrographia*, contains his own illustrations of cell structure. These illustrations, so beautifully and accurately carried out, served as a guide for generations of students of biology. Hooke made important observations on the nature of moulds, fungi and mosses, and his painstaking genius produced accurate studies of minute markings on fish scales, the foot of a fly and the minute structure of a bee's sting.

Much of his work was in physics: he invented the wheel barometer, and his suggestions for using barometric readings for the purpose of weather forecasting must have been an influence in later developments in meteorology. He suggested that the waves of light might be transverse vibrations. He investigated the nature of sound and the function of air in combustion and respiration. Hooke's achievements, it is thought, would have been even greater had his activities been less diverse.

He assisted Robert Boyle in the early days of the Royal Society, where he later became curator of experiments, and he was elected a Fellow in 1663. The degree of M.D. was conferred on him in 1696.

Unfortunately Hooke's career was marred by constant ill health; his shrunken limbs, haggard face and unkempt locks gave him a deplorable appearance and he was irritable, jealous and miserly. Though he held a lucrative employment as surveyor of rebuilding works after the Great Fire of 1666, he spent little, and after his death several thousand pounds were discovered hoarded away in an old iron chest.

HOOKER, Sir Joseph Dalton (1817–1911). Second son of the famous botanist, Sir W. J. Hooker, Hooker received his M.D. from Glasgow University and soon afterwards joined the expedition commanded by Sir James Ross as assistant surgeon on the *Erebus*. On his return from the Southern Seas he published an account of the flora which he had observed on the three years' voyage. His industrious and methodical arrangement of the plants of the Antarctic as well as those of New Zealand and Tasmania formed the beginnings of the systematic study of plant ecology.

Hooker's observation of plant similarities enabled him to suggest a possible land connection between South America and Australia in comparative recent geological times. Of great significance were Hooker's revelation of the important place in nature of the tiny marine plants called diatoms.

Hooker later made journeys to Palestine, Morocco, the United States and to the northern frontiers of India.

Hooker's widespread scientific investigations, with the material he published, soon firmly established his reputation. In 1855 he was appointed assistant director of the Botanical Gardens at Kew, succeeding his father as director ten years later. When only thirty years of age he was elected a Fellow of the Royal Society, and was later elected President.

Hooker was a life-long friend and warm supporter of Darwin, who consulted him frequently. At the British Association meeting of 1868, Hooker, from the Presidential chair, evinced his complete support for Darwin's theories.

Hooker's *Student's Flora of the British Isles* was for more than 80 years a standard work, and his great *Genera Plantarum*, in which Bentham collaborated, is based on the collections at Kew.

He was awarded the Order of Merit on his ninetieth birthday.

HOPKINS, Sir Frederick Gowland, O.M., F.R.S. (1861–1947). Prominent bio-chemist who did important research in connection with proteins and vitamins.

Hopkins was a pioneer in the study of deficiency diseases. He discovered that young rats fed on a diet made up of purified protein, fat and carbohydrate failed to grow, but immediately started to grow if minute quantities of fresh milk were added. He reasoned that the milk contained what he called accessory food factors without which there could be no growth nor complete health. Later workers identified and separated several vitamins (A, B, B_2, D) from milk.

Hopkins was professor of bio-chemistry at Cambridge. His public work included important analytical investigations which he carried out on behalf of the Home Office.

In 1929 he was awarded the Nobel Prize for medicine in recognition of his work.

He was president of the Royal Society from 1931 to 1936 and of the British Association in 1933.

HUTTON, James (1726–1797). Scottish geologist. As a youth he was articled to a lawyer, but on his employer's advice forsook the law and took up medicine instead, studying at Edinburgh and in Paris. Still not finding his true bent, he turned to agriculture. Through practical experience in the management of a small farm which he inherited, he became interested in improving farming methods and with this aim he embarked on a systematic study of the surface of the earth. Before this time there had been no serious geological investigation, but Hutton, in the course of many years' observation, concluded that stratification in the rocks is the result of processes of nature still at work at the present time. This view he set out as a Principle of Uniformity which is the accepted basis of modern geological theory.

His conclusions were laid before the Royal Society of Edinburgh in a paper entitled *Theory of the Earth* in 1785. Hutton's researches also produced new knowledge on the causes of rainfall and he made important contributions to the study of matter, light, heat and electricity. His published writings also embraced metaphysics and philosophy. Though Hutton did not live long enough to collect and arrange his numerous writings, the task was undertaken after his death by his friend Professor John Playfair, thereby making it possible for later geologists to reap the great benefit of Hutton's pioneer work.

HUMBOLDT, Baron Alexander von (1769–1859). German geographer. Made first map showing isothermal lines. Showed linear character of volcanic groupings.

HUNTER, John, F.R.S. (1728–1793). Scottish surgeon, born in Lanarkshire. One of the greatest of anatomists and now recognised as the founder of modern surgical science. He was surgeon at St. George's Hospital and later to the king. An ardent experimenter, he is said to have dissected five hundred different species of animals. To house the animal life he collected for his studies, he built a private menagerie. He was

JOHN HUNTER

earless in handling the animals and once, single-handed, re-captured two leopards which were escaping from their cages. He founded a museum to house his immense collection of specimens, which are now preserved at the Royal College of Surgeons. Hunter died through a disease with which he had injected himself to observe its effects.

HUXLEY, Thomas Henry (1825–1895). Although Huxley was a schoolmaster's son, he received little education, his father suddenly losing his employment when the head of the school died.

Huxley, who had an insatiable thirst for knowledge, gained a scholarship at Charing Cross Hospital, and having qualified at 20, winning the gold medal for anatomy and physiology, he was appointed surgeon to H.M.S. *Rattlesnake*, a survey sailing vessel on an expedition in Torres Strait.

The wealth of surface life in the tropical seas fascinated Huxley and in a corner of the ship's chartroom he studied the sea creatures he dredged up. Huxley's reports showed the necessity for a completely new outlook in zoological science. His brilliant investigations of the bodies of a great variety of animals and his discussions influenced successive generations of zoologists, as well as the young H. G. Wells. Huxley at first violently disagreed with Darwin's theory of evolution, but after reading Darwin's book *The Origin of Species* he took his place at the side of his celebrated contemporary and supported his views in the face of bitter opposition and hostility.

Huxley added his own testimony to the great debate in his book *Evidence as to Man's Place in Nature.*

THOMAS HUXLEY

HUYGHENS, Christian (1629–1695). Dutch astronomer and mathematician. Discovered Saturn's fourth moon and rings.

JEANS, Sir James Hopwood, O.M., F.R.S. (1877–1946). One of the leading British mathematicians and astronomers, Jeans studied at Trinity College, Cambridge, where he had a brilliant career and was elected a Fellow of his college. He was first a lecturer in mathematics and later professor of Applied Mathematics at Princeton University, U.S.A., returning to Cambridge in 1910. He was secretary of the Royal Society from 1919 to 1929, of which he was elected a Fellow. In 1923 he was Research Associate at the Mount Wilson Observatory in California. To Jeans is due much of the credit for making the sciences of astronomy and astro-physics intelligible to the ordinary man in the street. Before his time little had been done to popularise knowledge of the universe, but Jeans' clear approach to the general reader made a comprehensive view of astronomy possible for many to whom the subject had long been a mystery. Jeans carried out considerable research in the dynamical theory of gases and in cosmogony. Besides his more serious technical works such as *Problems of Cosmogony and Stellar Dynamics*, *Atomicity and Quanta*, Jeans' writings include *The Universe Around Us*, *The Mysterious Universe* and *The Stars in their Courses*.

JENNER, Edward (1749–1823). Jenner, the son of a Gloucestershire parson, was apprenticed to a doctor—the normal preliminary to a medical career at that time—and finished his training at St. George's Hospital in London, where he was a pupil of the famous John Hunter. Jenner then returned to his native Gloucestershire where he carried on his medical practice.

In Jenner's day smallpox was a disease that took a great toll of victims from rich and poor, and many of the cases were fatal. Jenner noticed that milkmaids often suffered from sores on their hands from milking but that the girls seldom contracted smallpox. Jenner thought that there might be a connection between infection by cowpox and freedom from smallpox, and that possibly one gave a form of protection against the other. He studied the question from many angles and found that cowpox only gave protection when the disease had developed to a certain stage. At last, when he felt reasonably sure that all his conclusions were correct, he took a daring chance and inserted cowpox matter into scratches he made in the arm of a healthy boy. Some time later he again inoculated the boy—this time with smallpox—and no ill effects ensued. This showed that the first inoculation, or vaccination (*vacca* is the Latin word for cow), had given protection against the smallpox germ; but it was by no means the end of the story, for Jenner's claims encountered fierce hostility from many of his medical colleagues.

But eventually the value of vaccination was recognised and Jenner received many public honours.

JOLIOT-CURIE, Jean Frédéric (b. 1900). Leading modern French experimental physicist who made a number of important investigations into the energy of electrons. In collaboration with his wife Irène Joliot-Curie, who is also a leading French scientist and the daughter of the discoverer of radium, he discovered artificial radioactivity.

In a cloud chamber Joliot observed a positive and a negative electron annihilate each other. When this happened, he concluded that two photons of electro-magnetic energy were emitted in opposite directions.

For his outstanding experimental work Joliot was awarded the Nobel Prize for physics.

He was High Commissioner for Atomic Energy, but was deprived of office, it is said, because of his communistic views.

He was chairman of the permanent Committee of the World Peace Congress.


JOLIOT-CURIE and Mme JOLIOT-CURIE

JOULE, James Prescott, F.R.S. (1818–1889). Celebrated physicist. He was a pupil of Dalton from whom he learned some chemistry, but most of his scientific training was obtained by his own efforts. He devoted himself to chemical and physical research, particularly in electro-magnetism. His main interest was in devising more accurate means of measuring quantities.

In a paper he read before the British Association in 1843, he claimed that the expenditure of mechanical energy must always produce an equivalent amount of heat energy. By experiments he performed he also demonstrated the validity of the law of the conservation of energy.

KEKULÉ, Friedrich August (1829–1896). German chemist who made important contributions to chemical theory. After studying in Paris, Switzerland and England, Kekulé established his own chemical research laboratory at Heidelberg, where he carried out important research. He was then appointed professor of chemistry at Ghent and later held a similar post at Bonn.

His discoveries relating to the ring-like arrangement of the carbon atoms in a molecule of benzene and covering the composition of other organic bodies cleared the way for the use of new methods of chemical decomposition and synthesis. It is considered that Kekulé's theories provided the key to a large part of modern organic chemistry and in particular the great extension of the industry concerned with extracting a wide range of dyes and other products from coal-tar.

KELVIN, William Thomson, Lord, P.C., O.M., G.C., V.O., F.R.S. (1824–1907). British physicist and inventor.

After receiving his early education from his father, a teacher of mathematics, Thomson studied at Glasgow and then at Cambridge, where he had a brilliant career. He then worked in Paris for a year and at 22 was appointed to the Chair of Natural Philosophy at Glasgow. During the half-century or more he occupied that position he was recognised as one of the greatest physicists of the day.

Thomson carried out a large number of experiments on thermometry, the cooling of gases on expansion, and in electricity. He concluded that a source of energy could not transmit energy if it was cooler than its surroundings because heat can travel only from a hot object to a colder one.

His researches laid the basis for modern thermodynamics and ultimately for the development of refrigeration. His work in connection with radiation and the age of the earth is of less importance because his calculations giving a small age to the earth were in error, since at that time terrestrial radioactivity as a source of heat was unknown. He invented the siphon recorder for the Atlantic cable and also an electrometer and sensitive galvanometer.

In recognition of his services, Thomson was created a peer, taking the title of Lord Kelvin. He was President of the Royal Society, Chancellor of Glasgow University and was awarded the Order of Merit. He is buried in Westminster Abbey.

KEPLER, Johannes (1571–1630). Kepler's mother was an ignorant woman whom his father, a dissolute soldier of fortune, deserted, and Kepler himself had poor health; to which disadvantages an attack of smallpox in babyhood had added crippled hands and poor eyesight. Kepler first earned his living in various theological posts but religious differences eventually excluded him from this form of employment.

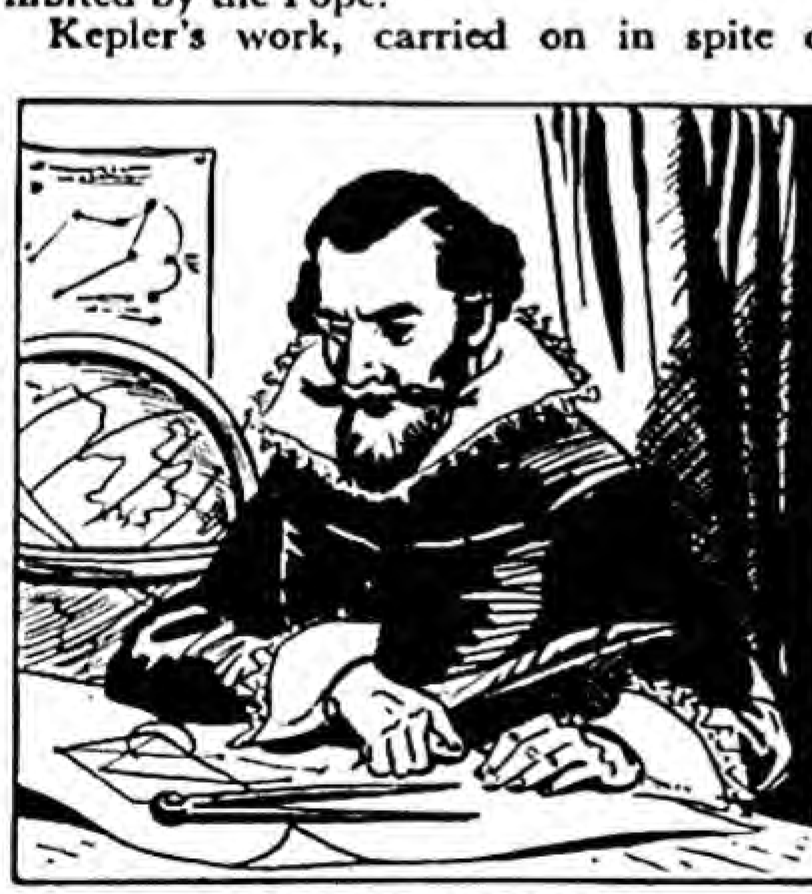
His interest in astronomy had already been awakened and an offer from Tycho Brahe of the position of assistant in his observatory at Prague solved the problem of his future. Tycho's death a short time afterwards left Kepler with the immense task of completing the Danish astronomer's astronomical tables.

Kepler afterwards formulated the planetary laws, sometimes known as "Kepler's Laws": (1) Planets move round the sun not in circles but ellipses, the sun being one of the foci. (2) A planet moves not at a constant rate but in such a way that a line drawn from it to the sun sweeps out equal areas of the ellipse in equal times.

It was not until nine years later that Kepler had worked out and was able to formulate his third law, which stated that the square of the period of the revolution of a planet round the sun is proportional to the cube of its average distance from the sun.

Kepler was enabled to discover these laws with the aid of the observations which Tycho Brahe had made. When his results were published they were denounced and his writings placed on the list of books prohibited by the Pope.

Kepler's work, carried on in spite of enormous obstacles, was little appreciated in his lifetime, but his great achievement in defining the movements of the planets made it possible for Newton afterwards to explain them in his theory of universal gravitation.



JOHANNES KEPLER

KIRCHHOFF, Gustav Robert (1824–1887). German mathematician and physicist. He made a considerable number of contributions to physical science in which he dealt in mathematical terms with problems of electrical conduction. He is chiefly known for his researches on radiation with R. W. von Bunsen, as a result of which they developed a complete system of spectrum analysis. Their most significant and outstanding achievement lay in showing that it was possible by this means to determine the chemical constituents of celestial bodies by a comparison of their spectra with those of various substances.

Kirchhoff and Bunsen proved the validity of their method by discovering two hitherto unknown elements, *Caesium* and *Rubidium*, and Kirchhoff was able to demonstrate the presence of certain elements in the sun.

KOCH, Robert (1843–1910). Noted German bacteriologist. Though Koch started life with little education and gained his livelihood from a small medical practice in a country district near Breslau, his investigations have been of the greatest value to medical science. He discovered that infectious diseases are carried by germs or microbes from one person to another and he identified the germs which produce anthrax, cholera and tuberculosis.

When anthrax broke out among the cattle in his district, he examined the blood of a sick animal under the microscope. By isolating the bacteria and cultivating them he traced their life history and found the best way of combating them. He showed that when the germs he had isolated from sick animals were introduced into the bodies of healthy animals, they would start to grow there and produce in the new host the same kind of illness.

Koch is one of the greatest bacteriologists in medical history. His methods have enabled scientists to discover the organisms which cause a large number of diseases. He developed bacteriology into an important and valuable science, using methods which are practically the same as those of modern bacteriologists. Koch was awarded many public honours, including the Nobel Prize for medicine.

KUHNE, Willy (1837–1900). German physiologist. Kuhne studied under a number of leading physiologists. After his graduation he was appointed head of the chemical department of the Berlin Pathology Laboratory and was successively professor of physiology at Amsterdam and Heidelberg. He carried out important researches in the physiology of nerves and muscles and in the chemistry of digestion, in which field he paid special attention to the study of the enzyme action (similar to the type of action already familiar to chemists as catalysis) which occurs in a number of processes in living creatures.

Kuhne considerably extended existing knowledge of these organic catalysts or ferments, to which he gave the name of enzymes.

ROBERT KOCH

LAMARCK, Jean Baptiste (1744–1829). French naturalist. Advanced use and disuse theory of evolution in which the inheritance of acquired characters was held to explain the origin of species by self-adjustment. His views are still fought over today and still lack experimental support.

LANGMUIR, Irving (b. 1881). Langmuir was born in Brooklyn and educated partly in Paris and later at Columbia College where he graduated. After studying in Europe under Nernst, he became chemistry instructor at the Stevens Institute of Technology, N.J., but later joined the General Electric Laboratories in Schenectady, New York.

The tungsten wire filaments used in vacuum in electric lamps disintegrate at 2,000°C. Langmuir found that if an inert gas such as argon is put into the bulb, the filament temperature can be raised to 2,500°C., because the gas reduces the tendency of the wire to volatilise. At the higher temperature of the "gas-filled" lamp, a greater proportion of the electrical energy used is radiated as light.

In the course of these experiments, Langmuir became interested in methods of securing a more perfect vacuum. For this purpose he designed a mercury condensation pump in which a blast of hot mercury vapour is used to siphon the air out of a container. From his study of vacuum tubes, Langmuir observed that the gas formed a single layer of atoms on the inside of the glass. This seemed to contradict previous theories about the behaviour of atoms and stimulated by the ideas of G. N. Lewis (1916) Langmuir made numerous experiments by which he was able to justify the theory that the valency electrons are in an outer shell around the atom. The nature of this shell in relation to the exchange of electrons between various atoms, determines the valency and other chemical properties of the atom (1919). Most of these ideas have been incorporated in Bohr's theory of the planetary atom. Langmuir also studied the way in which the surface layers of certain substances act as catalysts.

LAPLACE, Pierre Simon, Marquis de (1749–1827). Celebrated French mathematician. The son of a small farmer, Laplace revealed his mathematical gifts at an early age and he was scarcely 25 when he was beginning to establish a position among

astronomers and mathematicians second only to that of Newton.

In a paper presented to the Academy of Sciences he was able to bring forward proofs embodied in three laws, sometimes referred to as the Laws of Laplace, based on his own observations, of the stability of the solar system.

Laplace made an exhaustive study of the laws of probability which to the scientist has an important bearing on physics, astronomy and the incidence of phenomena.

LAVOISIER, Antoine Laurent (1743–1794). Lavoisier has been called the "Father of Modern Chemistry". His wealthy parents gave him an excellent education and encouraged his taste for natural science. When he was only 23 he was awarded a gold medal by the French Academy of Sciences for an essay on the best method of lighting for a large town. Lavoisier served on many official government bodies and his considerable public work included schemes he initiated for the improvement of crops and cattle breeding.

Lavoisier influenced scientific methods because he reasoned only from evidence obtained by actual experiment and never relied on guesswork. Before his time chemists had paid insufficient attention to the weights of substances used in their experiments or to those of the products they obtained. Lavoisier weighed and measured everything. He found that when sulphur and phos-

ANTOINE LAVOISIER

phorus were burned in air they gained in weight. Following his conviction that the gain in weight was due to combination with something in the air, he discovered the composition of the air and the nature of oxygen, thereby overthrowing the false "phlogiston" theory which held that something present in the fire was set free during burning. Lavoisier showed that all chemical reactions could be represented by equations and that the combined weights of the substances in the reaction were always equal to the weight of the substances produced.

Liebig said of him : "His merit consisted in that he infused into the body of science a new spirit. He discovered no new body, no new property, but he interpreted the discoveries of those who had gone before him in the light of quantitative measurements."

Unfortunately, as a member of a Government board he fell under suspicion of adulterating the soldiers' tobacco. He was tried and condemned and perished under the guillotine during the French Revolution.

LEEUWENHOEK, Anthony van (1632–1723). A Dutch microcopist who is generally regarded as the founder of the science of histology, or the study of the structure of tissues. Leeuwenhoek received no scientific training and his investigations seem to follow no definite method or plan. Yet he lived to be elected a Fellow of the Royal Society, and was a corresponding member of the Paris Academy of Sciences. This remarkable man, who first worked as a shop assistant and knew no languages but his native Dutch and who worked with the simplest form of microscope, which he built himself, made some of the most important discoveries and removed some of the wildest misconceptions in the realm of natural history.

Leeuwenhoek is thought to have preferred to use single-lensed microscopes of very short focus, although they were more difficult to use, because of the defect now known as chromatic aberration found in compound microscopes of that time.

In Leeuwenhoek's day people thought that the lower forms of animal life were simply bred from decay. Leeuwenhoek showed this to be wrong. In the tiny field of his microscope he saw that the weevils in wheat were not bred from the grain itself but from grubs hatched from eggs deposited by winged insects.

He described the minute structure of the flea, as perfect in its kind as the larger animals, and traced its life history, revealing that it did not spring to life spontaneously, as was thought, from dust or dirt, but in the same way as other insects. He brought to light the fact that the pupa of the flea is often attacked by a minute parasite. He examined the aphides that attack fruit trees. He found no eggs inside the very large number he studied, but he did find inside them much smaller aphides. As there were no male aphides, Leeuwenhoek concluded correctly that the female aphide reproduces by parthenogenesis.

Leeuwenhoek's researches ranged over a wide field. He found that the red corpuscles of the blood are circular in man and those of frogs and fishes oval.

He described the microscopic structure of the muscles, the lens of the eye, and the teeth, and showed the difference in the stems of monocotyledons and dicotyledons.

LIEBIG, Justus von (1802–1873). As a boy, Liebig watched his father, a dealer in gums and dyes, making experiments to improve the colours, and early in life he became intensely interested in chemistry. His career was at first a difficult and arduous one. There were few laboratories in Germany where the eager student could experiment and Liebig's private efforts to increase his knowledge while employed by an apothecary were accompanied by breakages, explosions and finally dismissal. Determination and a move to Paris eventually gained Liebig the practical experience he required and by the time he was little more than 20 he was professor of chemistry at Giessen. Here, with government aid, he later established a laboratory for teaching experimental chemistry. This laboratory rapidly became world-famous; Liebig's gift for teaching attracting students from all countries.

Apart from the great stimulus given by Liebig's methods to all branches of chemistry, his researches produced a great extension of general chemical knowledge. He improved the technique of organic analysis. His method of determining the amount of urea in a solution was a great step forward in bringing accurate chemical methods into medical practice. He discovered chloroform in 1831. Liebig devoted his later years to the study of the chemistry of animal and vegetable processes, publishing in 1840 his book, *The Applications of Organic Chemistry to Agriculture and Physiology*. One of the most important features of his many contributions in this sphere was his suggestion that plants derive the carbon for their food from the atmosphere and that this carbon is later returned to the atmosphere during the decay of the plants.

LINNAEUS, Karl (1707–1778). Swedish botanist. The son of a clergyman, Linnaeus was considered so backward at his studies as a boy that, instead of training him for the Church as they intended, his parents considered apprenticing him to a shoemaker or tailor. Through a benefactor to whom he had shown his collection of botanical specimens, he was enabled to attend university lectures. While a student at Upsala, he was prompted to examine the stamens and pistils of flowers and he conceived the idea of basing a system of classification on them.

In 1732 he travelled through Lapland to collect specimens on behalf of the Academy of Sciences of Upsala. In crossing the Peninsula on foot he suffered great hardship from cold, heat, hunger and insects but he brought back knowledge of a hundred new plant species.

He afterwards visited Germany, Holland, France and England. On his return he was appointed Professor of Natural History at Upsala. As a result of his published work he was now famous and students flocked to his lectures.

Linnaeus's achievement for which he is chiefly remembered is his system of classification of all living things, in which every known animal and plant was assigned its proper place and distinguished by means of a Latin name in two parts (genus and species), e.g. *Bellis perennis* for the common

KARL LINNAEUS

daisy. Although some of Linnaeus's arrangements have been revised in the light of later knowledge, his classification in its general form is used by all naturalists at the present day.

LISTER, Joseph (1827–1912). One of the greatest of English surgeons, Joseph Lister, the son of Quaker parents, was born in Essex. His father, the inventor of an improved compound microscope, was a Fellow of the Royal Society.

Lister was a surgeon at Glasgow Infirmary when the results of Pasteur's experiments were becoming known, revealing the presence in the air of the bacteria which spread diseases.

At that time, although the introduction of anaesthetics had eased the surgeon's task in some respects, great numbers of patients were dying even after slight operations.

When Lister came to Glasgow the infirmary was riddled with septic pestilence. Every care was taken to protect the patients from infection but the appalling death-roll was causing the very word hospital to be feared and even the best surgeons were beginning to despair. One type of wound rarely developed the fatal gangrene. In cases of simple bone fracture, where the skin had not been pierced, the patient usually recovered. Lister realised that it was through microbes conveyed to the wound that putrefaction was caused and he began to look for a way of killing the germs before they could multiply in vast numbers in the wounds. Carbolic acid used as an antiseptic (*against* germs) he found was too powerful and burning in its effect. So he decided that the alternative was to transform the operating theatre so that it was aseptic (*without* germs), instead. Soap and water was used plentifully to clean everything used in operations. Lister's methods succeeded and were after a time adopted in all hospitals. The operating theatre of today, with its tiled walls, the surgeon's spotless gown, gloves and mask and the nurses' uniform with the hair covered up are the outcome of Lister's teaching. Lister was honoured by being raised to the peerage; he became President of the Royal Society and was awarded the Order of Merit.

LOEB, Jacques (1859–1924). German-American physiologist. Made important studies in plant and animal behaviour, which he sought to explain in terms of mechanism.

LOEFFLER, Friedrich (1852–1915). German bacteriologist. Notable discoveries regarding ultra-microscopic viruses. With Frosch in 1893, showed that the agent of foot-and-mouth disease would pass unchanged through a porcelain filter.

LYELL, Sir Charles, F.R.S. (1797–1875). Lyell was originally called to the bar but became interested in geology through a course of lectures he attended at Oxford. What was lost to the law was geology's greater gain, for otherwise Lyell's great work, *Principles of Geology*, which, probably more than any other book, established the present direction of geological thinking, would never have been written.

Lyell made it clear, as had been supposed by Hutton, q.v., in his *Theory of Uniformity*, that rocks were still being laid down and the earth's crust still being changed by water, glaciers, sandstorms and earthquakes, just as in ancient geological times. Once this fact was realised, it became possible, by considering the effect of these processes in the past, to reconstruct the earth's history.

Lyell became a supporter of Darwin and upheld his views in the *Antiquity of Man*.

MALPIGHI, Marcello (1628–1694). Italian physiologist. One of the first scientists to make microscopic observations of the structure of animals and plants. He found that insects breathe by a system of tubes, called *tracheae*, which are connected to breathing holes along their bodies. He discovered and described the stomata on the undersides of leaves, the purpose of which was not realised until much later.

His most important discovery, made by watching under his microscope the circulatory system of a frog, was the part played by the capillaries in the circulation of the blood, thus carrying on the work of Harvey.

Throughout his career, Malpighi corresponded with the Royal Society of London and sent them a complete report of all his scientific investigations which they published in a series of special volumes.

MANSON, Sir Patrick, G.C.M.G., M.D., F.R.S. (1844–1922). Manson, who served as a medical adviser to the Colonial Office, has been called the "Father of Tropical Medicine".

In an attempt to trace the causes of malaria, a French army surgeon named Laveran had examined the blood of one of his patients and found a single-celled parasite. A few years later, this infection was traced to man from the bites of mosquitoes.

With Sir Ronald Ross, Manson showed that the female of one special kind of mosquito, the anopheles, was the host of a parasite which, when it reached a later stage in its development, became the organism which carried the disease. The mosquito injected it into the blood of those it attacked.

From this discovery, and by tracing the life cycle of the anopheles, it was seen that the way to prevent the spread of malaria fever was by destroying the larvae of the insects. This was done by draining swamps or by covering with a coating of oil pools of stagnant water which might provide it with breeding places. Through the work of Sir Patrick Manson with Sir Ronald Ross, very large areas of land once unfit for human habitation were brought into a healthy condition.

MASKELYNE, Nevil (1732–1811). The solar eclipse of 1748 which Maskelyne saw at the age of 16 aroused his interest in astronomy and determined his future career. At Cambridge he graduated as Seventh Wrangler and the Royal Society appointed him to make observations of the transit of Venus at St. Helena in 1761. During the voyage, he evolved the system of determining longitude at sea by lunar distances. At his suggestion, publication of the Nautical Almanac was started, giving lunar distances for a complete year for the assistance of navigators.

In 1722, at Mt. Schehallion in Scotland, Maskelyne carried out a celebrated experiment to determine the earth's weight by comparing the departure from the vertical of a plumb-line set up in two positions on opposite sides of the mountain.

MAXWELL, James Clerk (1831–1879). Notable British physicist who is reputed to have written his first scientific paper at the age of 15. He was Professor of Natural Philosophy at Aberdeen from 1856 to 1860 and then held the chair of Physics and Astronomy at King's College, London, until his retirement. Three years later he was persuaded to leave his Scottish estate to become the first Professor of Experimental Physics at Cambridge, where he helped to draw up the plans for the Cavendish laboratory, supervised its construction, and the equipping of it with apparatus.

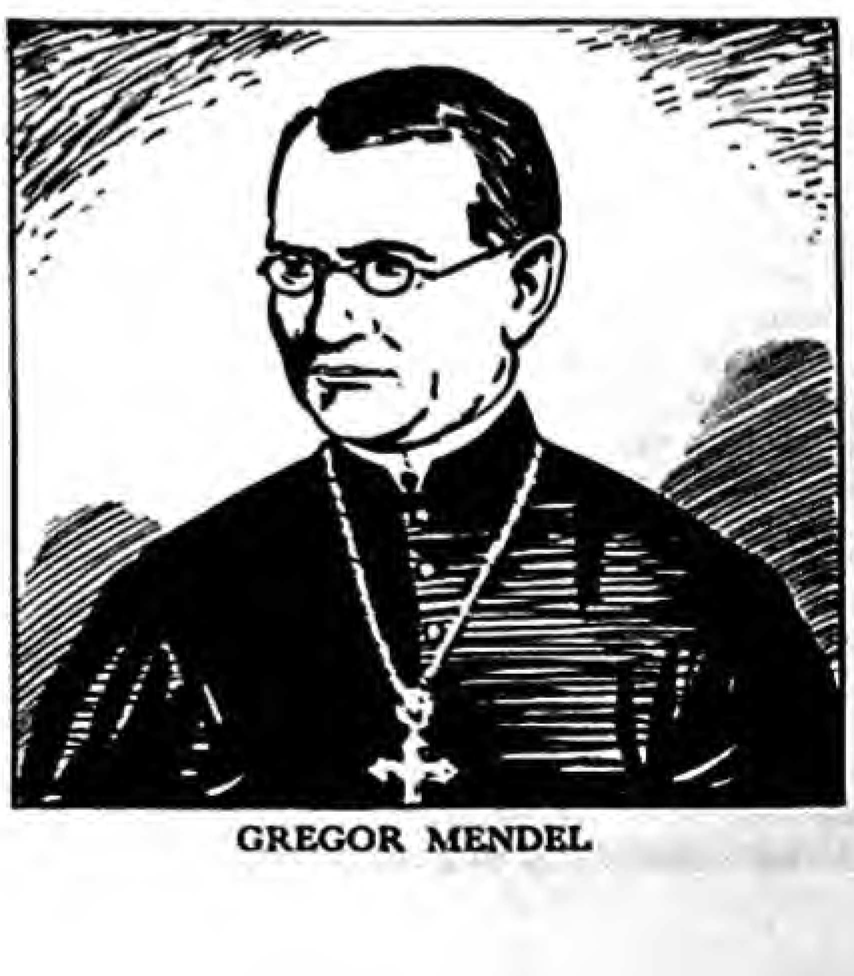
Maxwell's best known writings are *The Theory of Heat, Matter and Motion* and *Electricity and Magnetism*, which is considered to be among the greatest of individual contributions to mathematical science.

He made a mathematical study of the heat properties of gases which contributed to the investigation of thermodynamics. His mathematical theory of electromagnetism confirmed Faraday's experiments in the same field, and he was also to predict the existence of electromagnetic waves having the speed of light some years before they were discovered. These waves later became the basis of wireless transmission.

MENDEL, Gregor Johann (1822–1884). The son of poor peasants, Mendel entered a convent at Brno in Moravia as a boy and was ordained a priest. Later he studied at the University of Vienna, where he took a degree in physical science; returning to his convent, where he eventually became abbot. In the monastery garden, he spent his time carrying out a lengthy series of experiments in plant breeding by crossing tall pea plants with short pea plants, and he published his conclusions in a local journal.

Mendel's experiments and his conclusions revealed the laws that govern heredity, but the extraordinary fact is that, although many famous men of science were at that time seeking to discover these laws, Mendel's discoveries passed unnoticed.

At last, about twenty-six years after their publication and after his death, Mendel's reports were rediscovered at the moment when similar experiments to his were being made all over again by later research workers



GREGOR MENDEL

The Mendelian laws are now accepted as the basis of the science of genetics.

MENDELÉEF, Dmitri Ivanovitch (1834–1907). Russian chemist whose name has become famous because of his work on the Periodic Law, in which he showed that if the elements were arranged in order of the weights of their atoms, they fell into related groups; all elements having similar properties being in the same group. Having arranged them in this order, Mendeléef noted certain gaps in the tables, and from this he predicted the existence of certain elements then unknown and foretold their properties.

He was proved to be correct by the successive discovery within fifteen years of gallium, scandium and germanium, all three elements having the properties assigned to them by Mendeléef.

Mendeléef was born in Siberia, the youngest of a family of seventeen. He was left fatherless at an early age and despite the efforts of his widowed mother to support the family, they suffered extreme hardship and Mendeléef's work was carried out under incredible difficulties. He studied at St. Petersburg (now Leningrad) where eventually he became professor of chemistry.

Mendeléef wrote many books on various aspects of chemistry, his best-known work being *The Principles of Chemistry*.

For his work on the Periodic Law, he was awarded the Davy Medal of the Royal Society, which later bestowed on him the Copley Medal.

MICHELSON, Albert Abraham (1852–1931). Determined speed of light and sizes of stars.

MILLIKAN, Robert Andrews (b. 1868). Famous American physicist. Discovered cosmic rays. Measured the charge on the electron.

MOHL, Hugo von (1805–1872). German botanist. Named part of vegetable cell *protoplasm*, now a term of world-wide currency.

MOSELEY, Henry G.-J. (1887–1915). An Oxford physicist, one of the most brilliant scientists of the century, by whose death in the war of 1914–1918 physical science sustained an immeasurable loss.

In a series of experiments he carried out at Oxford just before the outbreak of war, Moseley investigated the periodic table drawn up by Mendeléef in which the chemical elements are arranged in the order of their atomic weights.

By bombarding the elements in turn with cathode rays, to make produce their characteristic X-ray spectra, and using a crystal to determine the wavelengths emitted, Moseley noted that the frequency of the characteristic lines in their X-ray spectra changed in an orderly mathematical fashion from element to element.

The importance of atomic numbers (which express the number of positive charges on the nucleus of any atom) was made clear by Moseley when at his suggestion, following his experiments, atomic numbers were substituted for atomic weights in the table and certain anomalies were then eliminated.

Moseley was killed in action in 1915 in the Gallipoli campaign. He was then 28.

MÜLLER, Johannes von (1801–1858). German physiologist who did important work on the mechanism of the senses. Müller was first a student at Bonn and then a professor and afterwards professor of anatomy and physiology at the University of Berlin.

Through his physiological researches, particularly on the nervous system, Müller greatly added to the then existing knowledge of the mechanism of speech and hearing. He also made careful chemical and physical investigations of the various body fluids such as the blood, lymph and chyle.

The ancient theory that man can have no certain knowledge of the external world received new support from his observation that the kind of sensation experienced does not depend on the nature of the stimulation of the nerves but on the nature of the sense organ. For example, light, or any kind of mechanical stimulus acting on the optic nerve and the retina, produces impressions of light.

Müller collected a vast amount of information relating to physiology, both in its chemical and physical aspects as well as dealing with human and comparative anatomy in his famous *Outline of Physiology*. This work, translated into English and published in London, greatly aided progress in the developing study of physiology.

MULLER, Otto Frederik (1730–1784). Swedish naturalist. Produced first description of diatoms.

NÄGELI, Karl (1817–1891). Discovered nitrogenous character of protoplasm.

NEEDHAM, Joseph (b. 1900). Contemporary biochemist known for his studies of the chemistry of developing embryos.

NEEDHAM, Dorothy (b. 1896). Discovered that the myosin of muscle is a protein with contractile properties, as well as having the property of being an enzyme.

NERNST, Walther Hermann (1864–1941). German chemist. Invented an electrolytic electric lamp based on heating the oxides of thorium and other rare metals. Advanced solution pressure theory of electrolytes.

NEWTON, Sir Isaac, F.R.S. (1642–1727). English mathematician who achieved fame by his great discoveries.

At the age of 26 Newton was Professor of Mathematics at Cambridge and some of his most important work was done while he was still in his early twenties.

He was the first to state the laws of gravitation. He realised that the same force which caused things to fall, kept the planets in their orbits. He also established the laws of motion that are fundamental to the study of dynamics. He also made historic discoveries on the nature of light, and was the first to split white light into a spectrum. He invented the calculus, a mathematical procedure for following the rate of change in any process. By his discoveries, Newton set the whole of scientific investigation on a new path. His great work, the *Principia*, was published in 1687.

He was Member of Parliament for Cambridge in 1688, Master of the Mint in 1699, and President of the Royal Society in 1703.

OERSTED, Hans Christian (1777–1851). The Danish scientist who discovered electromagnetism was the son of an apothecary. He first studied philosophy and afterwards became a Professor of Physics in Copenhagen.

It had long been thought that there was some connection between electricity and magnetism because steel objects which had been struck by lightning were afterwards found to have become magnetised.

Oersted was convinced of it, but although he had tried for years to trace the connection he had failed to do so. By accident, one day during one of his lectures, he passed a current through a bar of copper lying on his table beside a magnetic needle. He noticed that the needle was deflected as the current flowed through the bar and this gave him the answer he had been seeking. Oersted continued his investigations and found that glass, metals and other non-magnetic substances did not prevent the passing of the magnetic effect. He also discovered the circular lines of magnetic force round a long straight conductor.

Within a short time of Oersted's discovery becoming known, Ampère, in France, had discovered many of the magnetic properties of electric currents and was working out the mathematical relationship between electricity and magnetism.

Oersted's other achievements include his discovery of the compressibility of water.

His work, *The Soul of Nature*, was an influence in making the study of science more popular.

OHM, George Simon (1787–1854). German physicist, born at Erlangen. He was a Professor of Mathematics at Cologne and afterwards Professor of Experimental Physics in the University of Munich.

Although Ohm wrote extensively, much of what he wrote is not now considered of great scientific interest. The outstanding exception is his statement of the mathematical theory of the electric current. The formula which he enunciated, now called Ohm's Law, states that the strength of the electric current flowing in a circuit is equal to the electromotive force divided by the resistance of the wire.

Ohm's name is commemorated by being given to the unit of electrical resistance—the Ohm.

OSTWALD, Wilhelm (1853–1932). German chemist, a professor at Leipzig, famous for his researches in physical chemistry.

Ostwald, who supported the theory of ionisation expounded by Arrhenius, formulated a law for the rate of chemical reactions. He was awarded the Nobel Prize in 1909.

OWEN, Sir Richard (1804–1892). A celebrated biologist born at Lancaster who, after being apprenticed to a local surgeon, studied medicine at Edinburgh and then in London. As a student at St. Bartholomew's he came under the influence of the famous surgeon, John Abernethy, and through him became an assistant in the Hunterian Museum in the Royal College of Surgeons. In the course of his work there Owen derived a vast knowledge of comparative anatomy. He became Hunterian Professor at the Royal College and later conservator.

In 1856 he was appointed superintendent of the Natural History Department of the British Museum and through his efforts, the collection was separated from the main museum and given spacious quarters in its own building.

Owen made the acquaintance of Cuvier and studied with him in Paris. He wrote many works on comparative anatomy and palaeontology and his reports of the dissections he made of large numbers of animals are consulted by students of comparative anatomy and zoology. His work on the *Anatomy and Physiology of the Vertebrates* was regarded as the most important record of the subject ever produced.

One of Owen's most noteworthy discoveries was that of the parasite *Trichina spiralis*, the organism which causes trichinosis.

PASCAL, Blaise (1623–1662). Carried out experiments to demonstrate pressure of the atmosphere.

PASTEUR, Louis (1822–1895). One of the greatest of modern scientists, Louis Pasteur, the son of a farmer, was born in the Jura mountains in eastern France. His parents sent him to Paris to study and after his return home he taught mathematics at the Royal College of Besançon. Afterwards, he returned to Paris where he studied for a degree in physics and later received his doctorate. But it was as a biologist that he achieved fame.

He became professor at the University at Lille, in which district were many distilleries and breweries. Pasteur was asked if he could find a remedy which would prevent the beer from turning sour, as often happened. When he examined the yeast which is put into the beer to make it ferment, he found that in the sour beer rod-shaped bacteria were growing with the yeast, while in the sound beer the bacteria were globular. He found that the bacteria which spoiled the beer could be killed by heat, a principle now made use of in the process called Pasteurisation, which is also used to preserve foods such as milk.

Pasteur carried further the experiments of Spallanzani (1769) in connection with putrefaction and thereby finally disproved the notion of the spontaneous generation of life.

He made a special investigation which saved the French silk-worm industry from disaster when disease threatened to wipe out the silkworms upon which the silk-producers depended for their livelihood. Pasteur discovered that the disease was caused by the growth of a germ, and he showed the silk farmers how to recognise the germ-carrying worms and prevent them coming into contact with healthy ones. Pasteur, who was a contemporary of Koch (q.v.), also studied the causes of anthrax and elaborated (1881) the method of inoculating (or injecting) a preparation of weakened anthrax germs to increase the resistance of cattle to the normal germ. He extended the practice to cover virus diseases like hydrophobia (1885). Thus he laid the scientific foundations of the vaccination practice discovered by Jenner (q.v.) some 80 years later.

Pasteur was elected to the Academy of France in 1882. The Pasteur Institute in Paris was founded as a tribute to him with money subscribed by people in every part of France and countries abroad with the object of extending knowledge of inoculation and to prepare vaccines for the prevention of cholera, typhoid and similar diseases.

PAVLOV, Ivan Petrovich (1849–1936). Pavlov was the son of a village priest in a country district of Russia. When he was a boy he suffered from a physical infirmity, but by a course of exercises which he had devised, he cured himself. It is thought that this early experience may have influenced his interest in physiology. He graduated in science and medicine at St. Petersburg (Leningrad), and after studying in Germany, he was appointed director of the physiological department of the St. Petersburg Institute of Experimental Medicine.

He became absorbed in the study of conditioned reflexes and by experiments on dogs found out a great deal about the physiology of the nervous system. He found that if a hungry dog is shown food, his saliva flow is stimulated. If a bell is rung each time the dog is fed, eventually the flow of saliva is produced by the sound of the bell alone. The response to ringing of the bell is a *conditioned reflex*. Pavlov demonstrated that each conditioned reflex is connected with a particular part of the cortex of the brain and if that part is absent or deficient, the reflex will be lacking.

Not all of Pavlov's conclusions are accepted today, but the perfection of the elaborate technique of investigation he evolved entitles him to a place among the great scientists.

He was greatly esteemed for his kindly and sincere character. The Royal Society honoured him by electing him an honorary member and awarded him their Copley Medal.

PEARSON, Karl (b. 1857). Made detailed statistical researches into human heredity.

PERKIN, Sir William Henry, F.R.S., D.Sc. (1838–1907). Perkin's father, a builder, wished him to become an architect, but Perkin, whose greatest interest was in chemistry, to which he devoted all his spare time, obtained a post in the Royal College of Chemistry on leaving the City of London School. He still carried out spare-time experiments in the evening in a laboratory he fitted up in the basement of his father's house.

In an unsuccessful attempt to produce quinine artificially he was prompted to observe the effect of treating aniline sulphate with bichromate of potash. From the resultant aniline black he was able to produce a dye afterwards called aniline purple, or "mauve".

An important dyeworks having commented favourably on the new colouring substance, Perkin had it patented and with his father's assistance set himself up to manufacture it commercially.

The starting of the new factory was an important industrial landmark, for with it were laid the foundations of the coal-tar dye industry.

Perkin was successful in preparing other dyes and he also started the production of artificial scent, the first synthetic perfume being his invention. In later years he carried out important investigations in the sphere of pure chemistry.

For his work on coal-tar dyes the Royal Society awarded him the Royal Medal and he later received the Davy Medal of the Society in recognition of his general scientific work.

So important to industry was the invention of Perkin's purple that the fiftieth anniversary of its discovery was marked by an international celebration held in London and a knighthood was conferred on William Perkin. The centenary of the discovery was celebrated in 1956.

PERKIN, William Henry (1860–1929). The eldest son of Sir W. H. Perkin (q.v.); like his father, was educated at the City of London School.

He afterwards studied at the Royal College of Science and at Würzburg and Munich. He was Professor of Chemistry at Edinburgh and at Manchester and later at Oxford.

His researches in the polymethylene compounds and in other branches of chemistry gained him a reputation as the outstanding organic chemist of his period. He held the post of technical adviser to the British dyestuffs industry and most of his work, like that of his father, had an important industrial bearing. He was awarded the Davy Medal of the Royal Society in 1904.

PICKERING, Edward Charles (b. 1846). American physicist and astronomer. First detected a double star spectroscopically.

PLANCK, Professor Dr. Max (1858–1947). German physicist, professor at Berlin. He carried out numerous researches in connection with specific heat and radiation of energy. His indefatigable labours culminated in 1900, when to explain experimental results for radiation emitted by a black body, he enunciated his Quantum theory—a concept of energy as being not a continuous flow but consisting of minute packages called *quanta*, each quantum being a fixed amount, the energy of which varies in accordance with the frequency of the emission.

The Quantum theory was later applied by Einstein and by Niels Bohr, who used it in considering the problem of atomic structure. Planck was awarded the Nobel Prize for physics in 1918.

PRIESTLEY, Joseph (1733–1804). Celebrated English scientist and experimenter who was also a Unitarian minister, a schoolmaster and an ardent reformer who suffered for his political and religious views. Although Priestley was not a scientist by training, he was greatly interested in experimenting and the discoveries he made were of such importance that the Royal Society elected him a Fellow. He invented the pneumatic trough for collecting the various gases which he prepared and also originated other greatly improved methods of preparing and studying gases. He found that green plants gave off a gas that could be breathed and that their presence made air that had been breathed fit to be breathed again. He discovered oxygen at the same time as Scheele but independently.

He wrote the *History and Present State of Electricity*, in which he provided a comprehensive review of electrical knowledge at that time.

Unfortunately, Priestley's political views made him unpopular. He wrote a pamphlet

expressing sympathy with the French Revolution and the radical opinions expressed in it were disliked by people in Birmingham where he was a minister. An angry mob wrecked Priestley's chapel and then set fire to his house, destroying his instruments and possessions. Priestley escaped, but life in England for him was no longer possible and he emigrated to America where he lived until his death.

PROUT, William (1785–1850). English physician who wrongly supposed that all atomic weights would prove to be whole numbers, thus indicating all atoms to be made up of hydrogen atoms.

PYTHAGORAS (b. 582 B.C.). Greek philosopher and mathematician, many of whose theories anticipated those of modern scientists.

QUETELET, Lambert (1796–1874). Belgian astronomer. Successfully applied the relationship of statistical methods to the analysis of human traits.

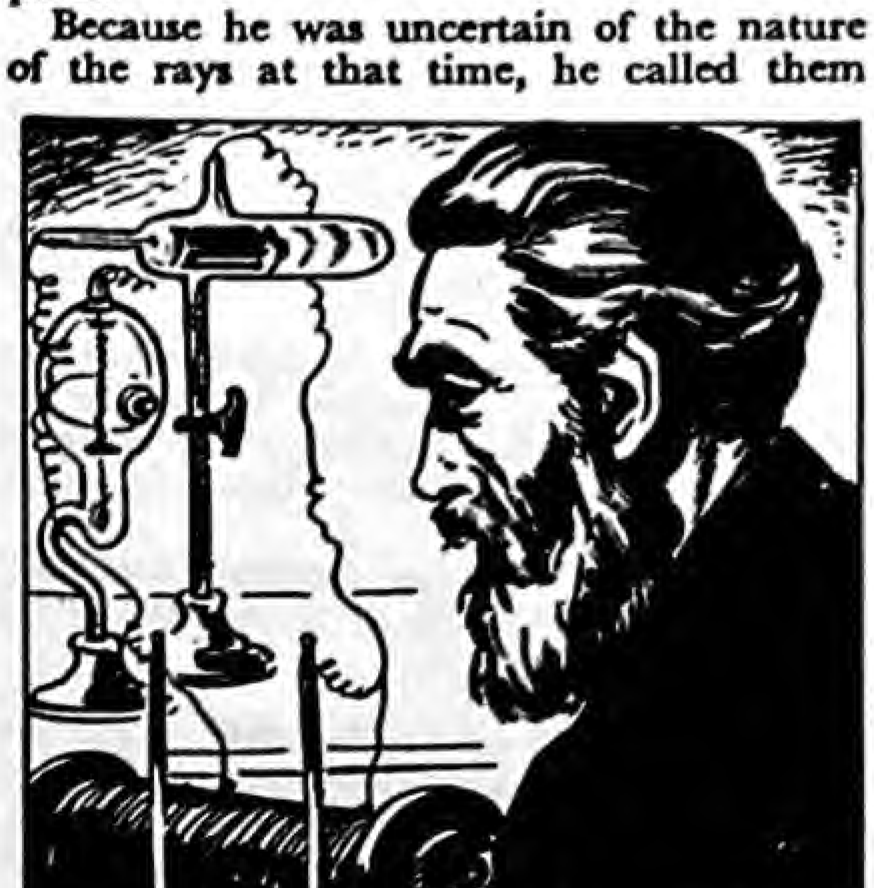
RAY, John (1627–1705). English naturalist. Made early systematic classification of animals and plants. Originated terms *dicotyledon* and *monocotyledon*.

ROEMER, Olaus (1644–1710). Danish astronomer. From observations of eclipse of one of Jupiter's moons, calculated speed of light.

RÖNTGEN, Professor Wilhelm Konrad (1845–1923). Eminent German physicist who discovered X-rays.

Röntgen went to school in Holland and then studied at Zurich where he took his doctor's degree. He held professorships at several universities and eventually was professor of physics at the University of Wurzburg. It was here that he noticed that crystals of barium platinocyanide glowed when an electric discharge was passed through a vacuum tube which was on the same bench. Further experiments which he carried out showed that a radiation was being emitted from the anode of the discharge tube and this was able to pass through various substances, such as black paper or card, and to affect a photographic plate.

Because he was uncertain of the nature of the rays at that time, he called them X-rays. For his discovery, Röntgen received the Rumford Medal of the Royal Society jointly with Philip Lenard who had also obtained some similar results in regard to cathode rays.



WILHELM KONRAD RÖNTGEN

ROSS, Sir Ronald (1857–1932). British scientist. Celebrated for his demonstration that the malaria parasite is carried by a mosquito encysted in the wall of its stomach.

RUMFORD, Count (Benjamin Thompson) (1753–1814). American physicist. On the basis of experiments in boring gun-barrels, established that heat is a form of energy produced by friction (or rubbing).

RUNGE, Friedlieb Ferdinand (1795–1867). Showed in 1834 that coal-tar contains small amounts of aniline.

RUTHERFORD, Lord, O.M., F.R.S. (1871–1937). Celebrated physicist born in New Zealand, and educated at Canterbury College; winning a scholarship to Cambridge. Here he worked with Sir J. J. Thomson, whom he succeeded in 1919 as Cavendish professor after holding professorships of physics at McGill and Manchester Universities.

Using very simple but most ingeniously contrived apparatus, he examined the processes of radioactivity. From his observations and measurements of the behaviour of alpha-particles coming from radioactive sources, Rutherford enunciated the nuclear theory of the atom in 1911. Eight years later, he split the atom for the first time, using these alpha-rays. His discoveries opened up the enormous possibilities of atomic energy and paved the way for later advances in atomic research. In 1908 he was awarded the Nobel Prize for chemistry. He was knighted in 1914 and later raised to the peerage.

SCHEELE, Karl Wilhelm (1742–1786). Scheele was apprenticed, at the age of 14, to an apothecary in Gothenburg and as a lad he often worked far into the night, studying and carrying out experiments. By this early practice he developed his brilliant technique as an experimenter.

Eventually Scheele became the owner of a pharmacy which, through neglect, had lost the goodwill of most of its customers, but despite the fact that he spent several years in bringing the business back to a sound condition, he found time for an enormous amount of original research and produced a lengthy series of discoveries and significant scientific commentaries.

He described in his *Treatise on Air and Fire* (1777) experiments in which he found that air consisted of two "fluids" which he called "fire air" and "foul air". Later these gases were given the names of oxygen and nitrogen by other chemists.

As an investigator Scheele was unequalled for his methodical approach and his scrupulous accuracy. He refused to be satisfied about the nature of any compound until he had broken it down and re-made it. He discovered chlorine, manganese, baryta, silicon tetrafluoride, hydrofluoric acid, copper arsenite and a long list of other substances. He also prepared phosphorus for the first time from bone ash. He traced the cause of acidity in sour milk to what is now known as lactic acid, and recognised that plants produce what we call carbon dioxide.

His vast labours, often carried out at night, led to an illness which caused his early death shortly after his marriage.

SCHLEIDEN, M. J. (1804–1881). German botanist. Established the theory of the growth of the cellular tissues of a plant as the result of a sequence of divisions of an original unit cell.

SCHROEDINGER, Erwin (b. 1888). Austrian scientist who introduced a new mathematical treatment called wave mechanics into atomic physics.

According to Schroedinger, an electron has some of the properties of a particle and some similarities to a wave. Instead of the electron orbits of the Bohr atom, he described the atom in terms of a system of stationary waves (interference effects between two sets of mathematical wave systems).

For his work on the theory of atomic structure Schroedinger was awarded the Nobel Prize in 1933.

SCHWANN, Theodor (1810–1882). Established a cell theory similar to that of Schleiden to cover the development of multi-cellular animals.

SIMPSON, Sir J. Y. (1811–1870). Scottish surgeon. Pioneer in the discovery and employment of anaesthetics.

SMITH, William (1769–1839). English geologist who is often called the Father of Modern Geology. In the course of his work as a civil engineer in making surveys for canals, he noticed certain regular features about the geological structure of the country. He found that when canals were being cut the excavations always reached the different geological strata or layers of rock in a definite order. Smith had always been interested in fossils, and he now observed, and verified by extensive researches, that whenever fossils were found, each layer contained its own particular kind. For example, fossils of plants would appear in a certain stratum, while in the layer beneath would be fossils of shelled animals, and in the next lower layer, the remains of different animals would be found.

There were exceptions to this rule in that in some cases the same kind of fossil would be found in the layer above and even in the layer below in addition, showing that the changes in the animal and plant life denoted by the fossils occurred gradually. He also recognised that fossils could be used to recognise the same rock bed where it outcropped at the surface in widely different areas.

William Smith's work, *A Stratigraphical System of Organised Fossils*, which demonstrated the important principle he had discovered, was published in 1817.

He produced the first coloured geological map of England and Wales with part of Scotland in 1815.

SODDY, Sir Frederick, M.A., LL.D., F.R.S. (b. 1877). Professor of chemistry at Aberdeen and later professor of inorganic and physical chemistry at Oxford.

Professor Soddy carried out extensive research in physical chemistry; his most

important work being concerned with radioactivity. Soddy was one of the pioneer investigators in the field and his work established the basis of the isotope theory before the subject had become the general focus of atomic research. He discovered that certain atoms had identical chemical properties but different masses and these were given the name of isotopes. The transformations in the breaking up of radium and uranium were studied by Soddy and his assistants. In collaboration with Rutherford he found that uranium changes spontaneously into radium and that radium likewise changes of its own accord into lead.

Professor Soddy has written a number of important works on radioactivity and the structure of the atom. A number of his published works deal with economic aspects of science.

STOKES, Sir George Gabriel (1819–1903). A foremost physicist and mathematician. Valuable researches and contributions to wave theory.

THALES (640–546 B.C.). Greek astronomer, geometer and philosopher born in Miletus, Asia Minor. Early seeker for a theory of matter.

THOMSON, Sir Joseph John, O.M., D.Sc., F.R.S. (1856–1940). Celebrated physicist and mathematician who graduated at Manchester and became Cavendish Professor at Cambridge at 28.

The Cavendish Laboratory at Cambridge, under his influence, became a centre of experimental science famed throughout the world and a great number of scientists who received their training under Thomson became outstanding physicists; many of them receiving Nobel Prizes for their work.

Thomson's brilliant experimental research was in the conduction of electricity through gases. He carried out experiments following up Crookes' work with the cathode-ray tube, to determine the charge and mass of the electron, which he discovered. He also investigated the positive rays emerging from an aperture in the cathode of the cathode-ray tube. Ultimately, his researches and discoveries made sound broadcasting, television and radar possible.

He was awarded the Nobel Prize for physics in 1906 and the Order of Merit in 1912. He was knighted in 1908.

TORRICELLI, Evangelista (1608–1647). Constructed first barometer to measure atmospheric pressure.

UNVERDORBEN, Otto (1806–1873). German chemist. First obtained aniline by heating indigo, though it was not named aniline until 1841 by Fritzsche.

UREY, Harold C. (b. 1893). Celebrated American chemist born in Indiana. Urey studied at the University of California where he gained his doctor's degree under Niels Bohr.

Following the discovery of the neutron by Chadwick, Urey made a further discovery which has very great importance in physiology and medicine.

From analysis of the spectrum of ordinary hydrogen, Urey had suspected the presence in it of an isotope of hydrogen of mass 2—double the normal—in minute quantities. With his collaborators, he carried out investigations at Columbia University and by electrolytic methods and spectrum analysis, they established the existence of the new isotope, *heavy hydrogen*.

This heavy hydrogen has been given the name of deuterium and its nucleus is called the deuteron.

Although the amount of deuterium present in ordinary hydrogen is less than one part in 4,000, it has since been found possible to prepare heavy water (water containing deuterium instead of hydrogen) in fairly large quantities.

VINOGRADSKY. Found in soil bacteria that could fix nitrogen from the air in the building of their bodies.

VIRCHOW, Rudolf (1821–1902). Medical science advanced by his researches in growth of cells in diseased tissues.

WALLACE, Alfred Russell (1823–1913). Celebrated English naturalist who was trained as an architect. In the company of a friend, he made an expedition up the river Amazon, but with the exception of the papers he had sent home, all his collections and notes were lost in a fire on the ship in which he was returning. On a later voyage to the Malay Archipelago he gathered a vast insect collection which is now in the Hope Museum at Oxford and the British Museum. Wallace's records of the types and geographical distribution of animals in various parts of the world are among the most important made by any naturalist. Wallace noted that the fauna of the Malay Archipelago was divided into two groups—a western group where the animals were of Oriental type and an eastern one where they were of Australian type. The imaginary line separating them is still known as the "Wallace Line".

From his own observations, Wallace independently reached the same conclusions as Darwin regarding evolution and natural selection. Muffled in blankets during an attack of ague, he wrote out his theory and sent it to Darwin in England, where both his and Darwin's papers, expressing the practically identical conclusions of both naturalists, were read together before the Linnaen Society in 1858.

In the cottage to which he retired near Godalming, Wallace grew nearly 1,000 species of plants.

He was awarded the first Darwin Medal of the Royal Society and later the Royal Medal. Oxford and Dublin Universities conferred honorary degrees on him.

WILSON, Professor C. T. R. (b. 1869). Wilson worked under J. J. Thomson as a research student at the Cavendish Laboratory of Experimental Physics in Cambridge, where he devised means of providing visible evidence of ionising radiations. He experimented for several years to perfect a camera which would photograph particles shot out during radioactivity.

He found that in an atmosphere saturated with water vapour, ions act as condensation nuclei in the same way as particles of dust. Using this knowledge, Wilson invented his cloud chamber. In this apparatus, the path of an alpha particle is made visible as it dislodges thousands of electrons from the gas molecules with which it collides, making these molecules to become positively charged —i.e. to become +ve ions. On these ions minute drops of moisture will settle The air is cooled suddenly to cause condensation, when the particle tracks can be then seen as fine lines and be photographed.

Wilson's cloud chamber, with some improvements, has proved indispensable in the investigation of atoms. Without it many of the known atomic particles could not have been so closely observed.

WOLFF, Caspar Frederick (1733–1794). German biologist whose researches laid the basis for modern theory of cell structure.

VAN'T HOFF, Jacobus Hendricus (1852–1911). Dutch chemist and physicist. After studying at the university of Leyden and in Paris, he took his doctor's degree at Utrecht where he became a lecturer and was later professor of chemistry, mineralogy and geology at Amsterdam. In 1896 he was given a salary and laboratory at the Prussian Academy of Sciences with freedom to devote himself to studying the relationship of mathematics to chemistry. His work in this field brought him international repute. From his investigations he was able to produce the first mechanical theory of valency. He explained the laevo and dextro varieties of certain organic compounds in terms of molecules that are mirror images of one another.

For his scientific work, van't Hoff received the Davy Medal of the Royal Society jointly with J. A. le Bel, who had been working independently on parallel lines. Van't Hoff conducted considerable research into the theory of solutions and proved that the osmotic pressure of a solution has the same value as the pressure of a gas at the same concentration. In 1877, he enunciated a theorem concerning the law of mass action.

VOLTA, Alessandro (1745–1827). One of the foremost figures in electrical science, Volta was professor of physics at Como, his birthplace, and he later occupied the chair of physics in Pavia. Volta studied the results obtained by Galvani and found that the latter's experiments in muscle stimulation owed nothing to the animal relationship as had been thought.

Volta's celebrated device of the voltaic pile, in which a series of zinc and copper discs were placed between cards soaked in brine or acid, causing electricity to be generated through chemical action, was the first instrument for producing electrical current.

In 1801, Volta went to Paris where he was received by Napoleon for whom he demonstrated his experiments on contact electricity. A medal was afterwards struck in his honour.

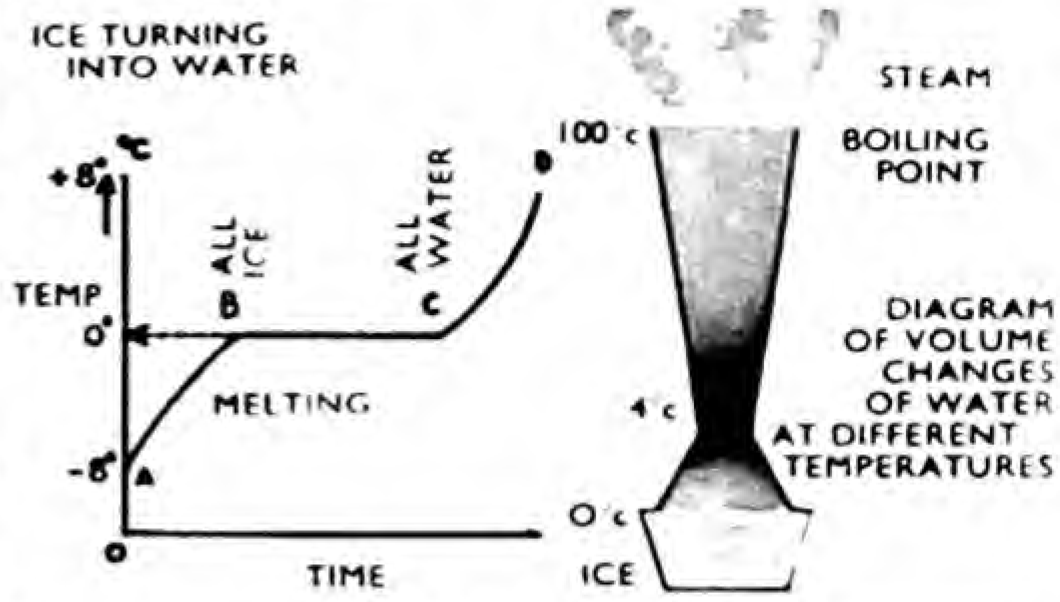
The unit of electrical pressure, the Volt, was named after Volta in recognition of his services to science.

YOUNG, Thomas (1773–1829). Proved the wave theory of light by experiments on the interference between light rays. Fresnel, in France, made the same discovery at about the same time.

FREEZING, BOILING AND MELTING

When, on heating, solids turn to liquids or liquids turn to vapour, there is a taking in of heat while the change takes place. Heat is also given out in the reverse process—cooling. This heat is called latent (hidden) heat.

In cold weather a cylinder block in a car is sometimes cracked because the water in the water jacket increases so much in size when it freezes. Anti-freeze mixtures are solutions which have lower freezing points than water, nor do they expand much on freezing.

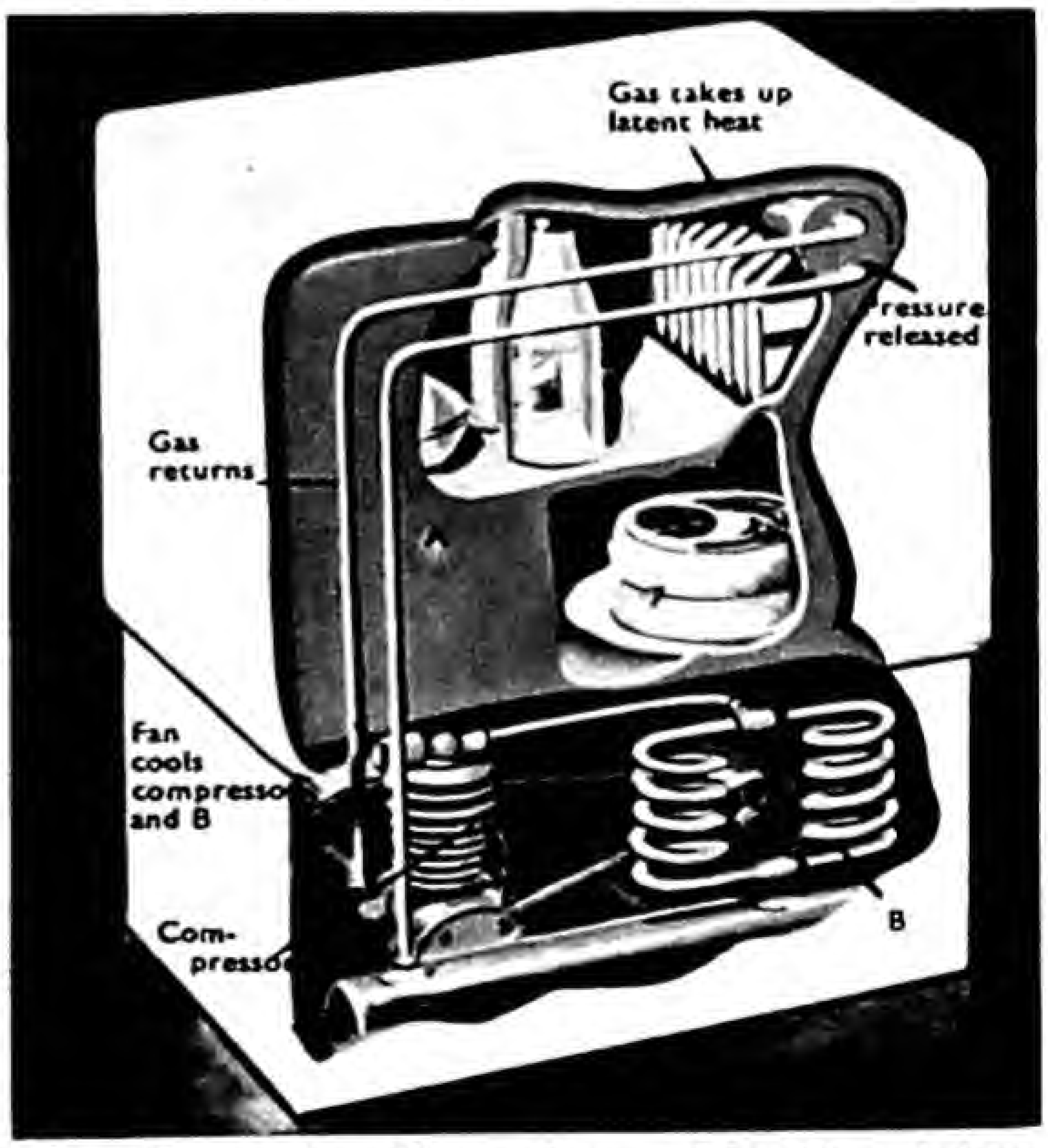


Because of latent heat effect, cooling water does not get any colder until all of it has turned to ice, and boiling water does not get any hotter until it has all turned to steam. Only then does the rise or fall in temperature continue.

(*Above right*) Water contracts when cooled. Shortly above its freezing point (at 4°C) however, it starts to expand. On turning to ice it expands still more but later contracts a little.

Molecules of any liquid move faster as it gets hotter and more and more break free of the surface to become vapour. With less atmospheric pressure on the liquid fewer of these molecules return into it. It therefore boils at a lower temperature.

Pressure applied during cooling makes freezing point go down below 0°C. Skating on ice is possible because the narrow blade pressing on the ice makes a pressure so great the ice cannot remain frozen. A tiny channel melts and in this the skate blade fits so the skater can stay upright.



One form of refrigeration. Liquid sulphur dioxide passes under pressure into the coils of the cooling pipe A. When the pressure is released it turns into a gas, taking up latent heat by cooling the contents of the refrigerator. The gas is then forced by the compressor into a condenser B, where it turns back to a liquid.

THE THREE WAYS HEAT CAN TRAVEL

By Conduction

This is the scientific name for the first way heat spreads, by travelling along something which is touching the source of the heat. Metals, for instance, conduct heat easily but some things like glass or brick

A lab method of measuring heat conductivity. Wax on the conductors melts further in a minute on the best conductor.

The heat from the fire warms the metal ovens by conduction until they are hot enough to cook meals.

do not. The only way to stop heat spreading by conduction is to cover the source with a non-conductor, which is quite often something that contains small pockets of air, like sawdust or wool, for still dry air does not conduct, although moving air conveys heat by the second method—convection.

The blacksmith cannot touch any part of the iron horseshoe, although only one end is red hot. He must use long tongs of steel to ensure that the heat has far to travel before it reaches his hands.

The glass blower can put his lips to the glass tube although the end of it is white hot because the heat will not travel easily through glass which is a bad conductor.

GOOD CONDUCTORS OF HEAT

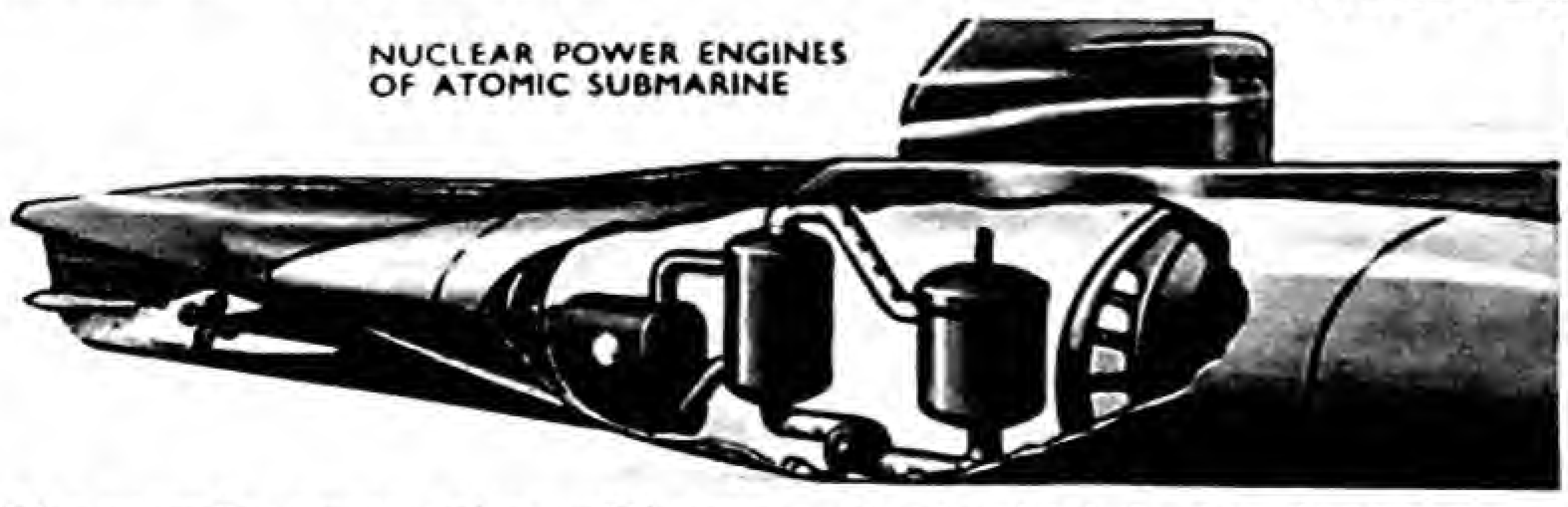
Steel
Iron
Brass
Copper
Tin

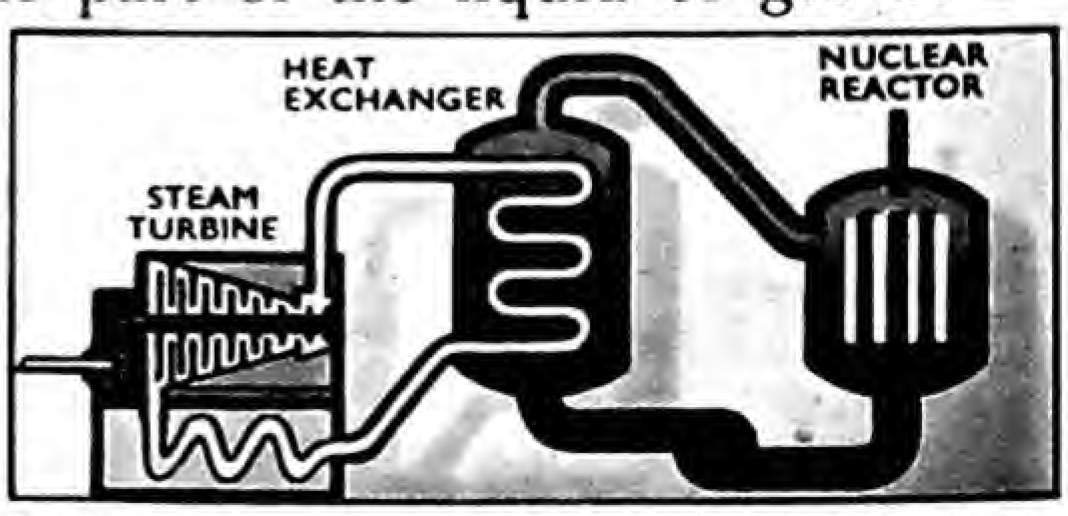
BAD CONDUCTORS OF HEAT

Wood
Glass
Air
Dry Paper
Water
Dry Wool
Dry Straw
Asbestos
Plastic
Rubber
Leather

By Convection

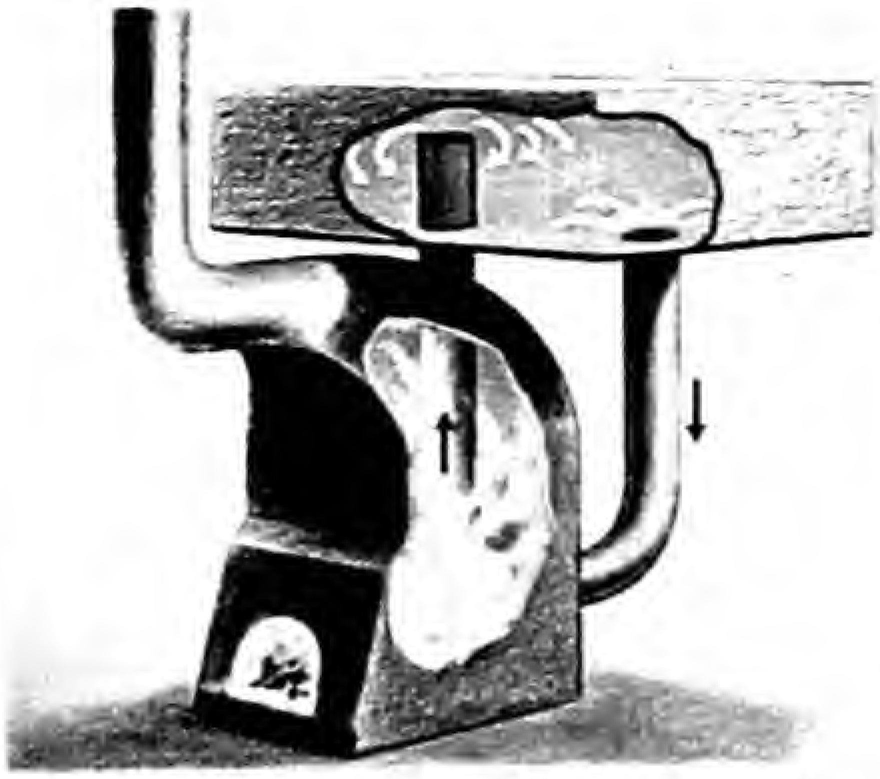
When one part of the liquid or gas in a





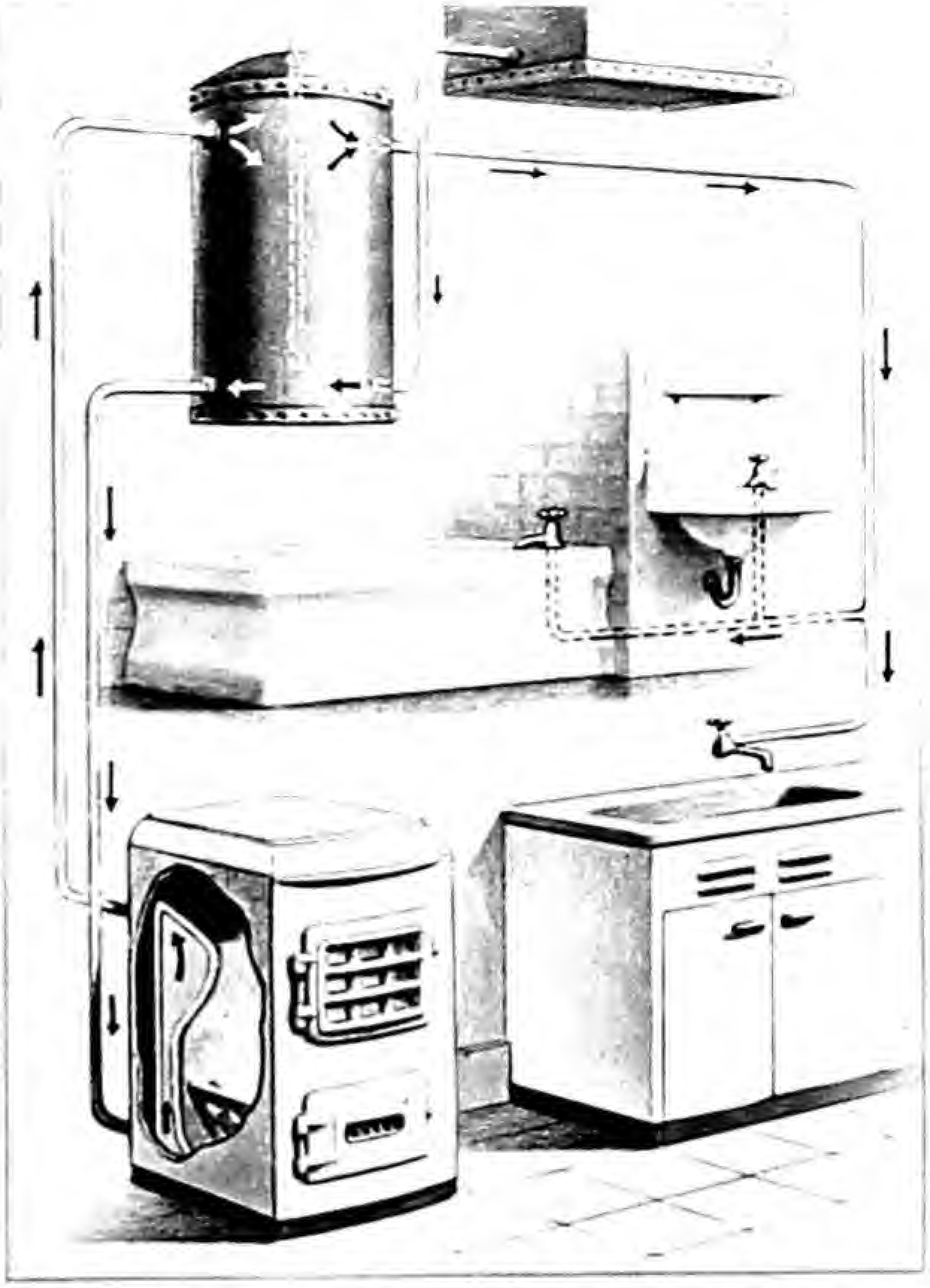
The atomic reactor gives off immense heat which is absorbed by a melted metal, sodium. This is led through pipes that conduct the heat to water so making steam, which then, by convection, rises to drive the turbine engines.

This laboratory experiment shows convection. As the permanganate crystals dissolve they mark the streams of hot water as they rise.



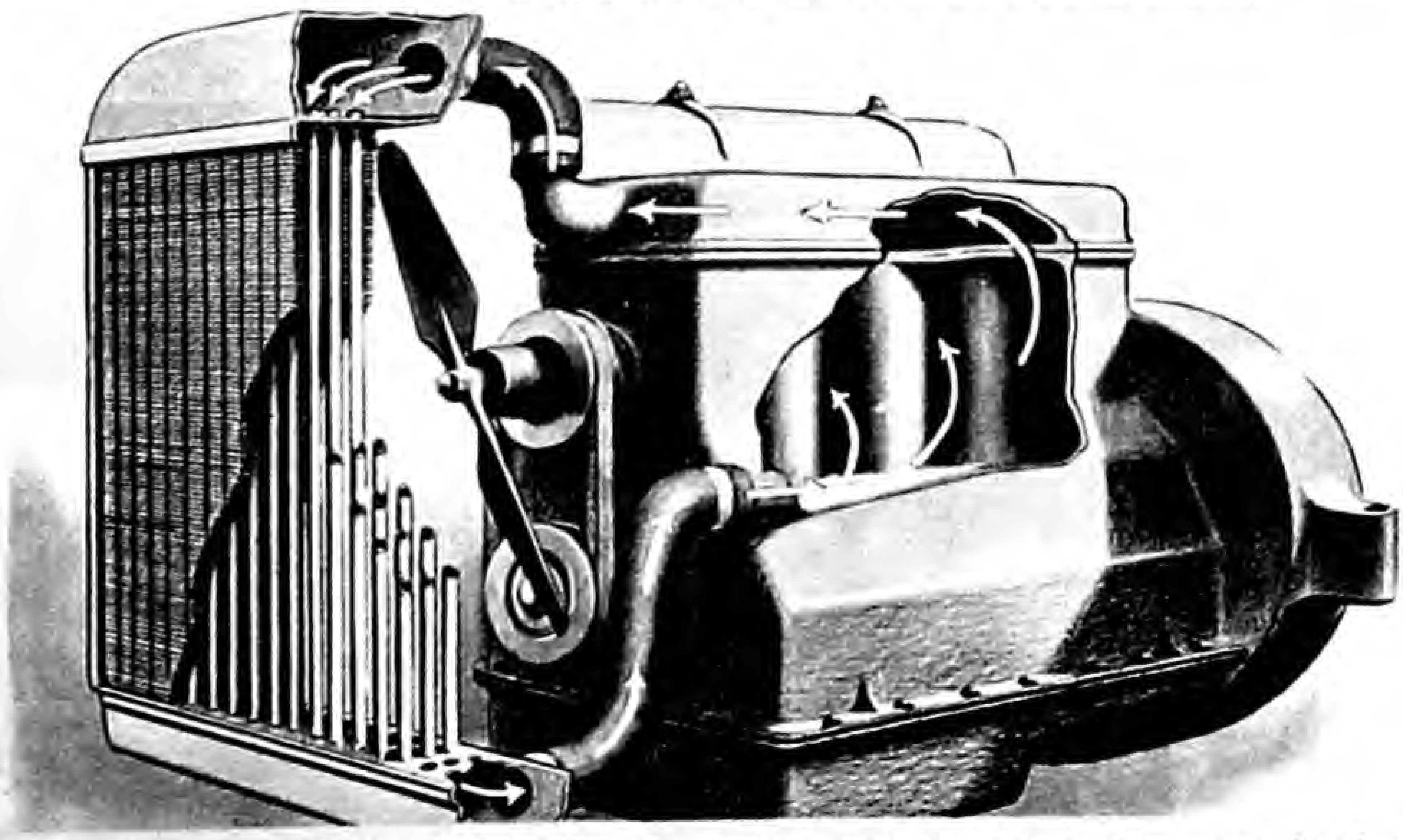
The first type of water tube boiler. Only one side of the "U" tube is heated by the furnace gases. The hot water and steam rises into the tank. As it cools it comes down the other side of the "U" to be heated again.

container is heated, it rises above the remainder because it expands. This is called convection. At the top it is cooled and therefore sinks again. As a result the liquid or gas moves round in a circle, taking heat upwards at the same time. To stop the spread of heat by convection the liquid or gas must be prevented from moving or be replaced by a vacuum.



The water jacket of a household boiler gets heat from the fire by conduction. Convection makes the hot water rise to the hot water tank and when it cools it falls back to the boiler for further heating.

The advertising dancer seems to move for no reason but inside a lamp heats air which, rising, drives a propeller and turns her.



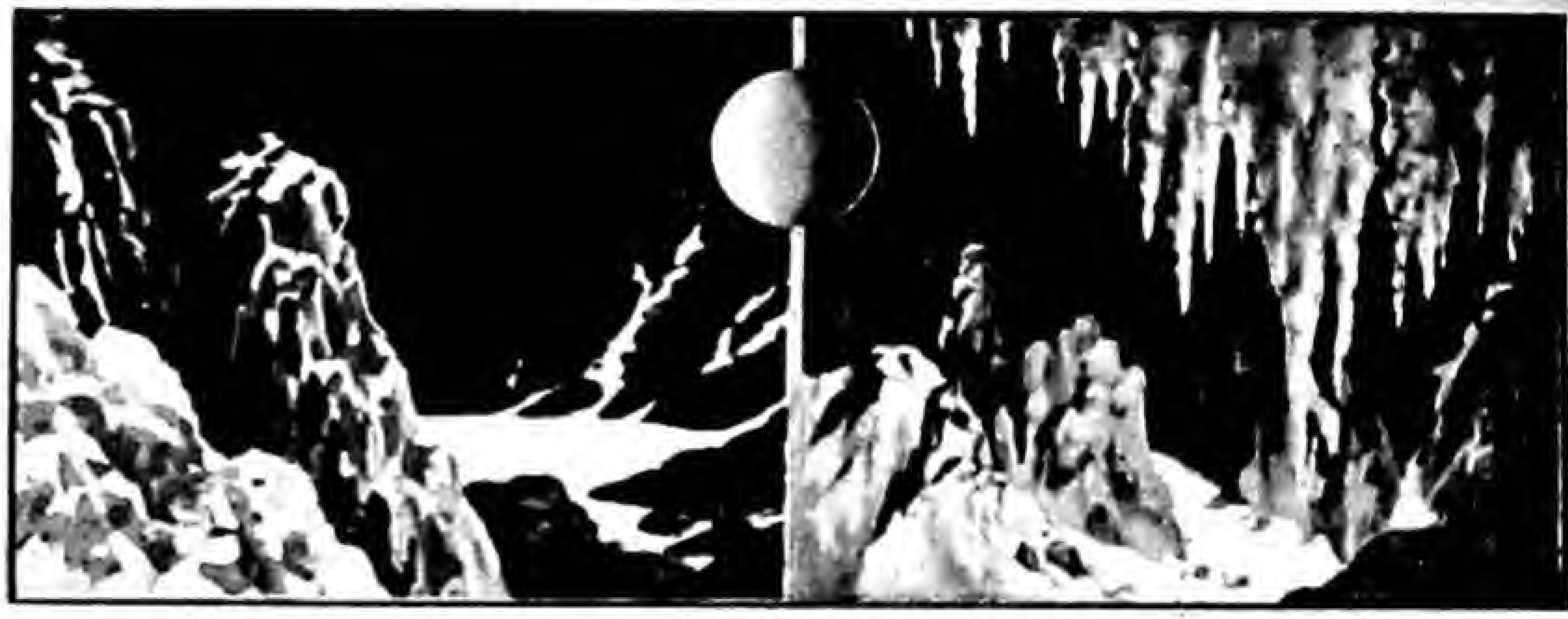
In cooling the cylinders heated by the explosions inside them, the water in the water jacket of a car engine receives heat by conduction through the metal. Convection takes the heated water to the top of the radiator where it is cooled by the flow of air and therefore sinks to the base of the radiator. From here it is returned to the bottom of the cylinder water jacket.

By Radiation

Radiated heat travels through the air, scarcely warming the air itself, yet heating anything solid it meets. It cannot turn corners, nor can it heat anything behind the first solid thing it meets.

Heat loss by radiation is very difficult to stop since any barrier will itself re-radiate the heat. The best way is to reflect the radiant heat with a mirror and so make it radiate back again.


All the heat rays are absorbed by the first thing they meet. The man in the overcoat in the right-hand picture is getting no heat from the fire because the two people in front of him are absorbing it all. If you sit farther from the fire you get less heat, not because it is lost on the way, but because the same amount of heat is spread over a bigger circle.



One planet, Mercury, spins on its axis once in the time that it takes to go round the sun. So one side faces the sun all the time and has streams of molten tin on it. But the other side gets no heat at all for the rays of the sun are all absorbed by the side that faces the sun.

This plan of the solar system shows how the sun's heat continually spreads itself over bigger spheres as it travels outwards to the orbit of each planet. A square foot of the surface of Mercury gets more heat than a square foot of Pluto. Mercury, near the Sun, gets the heat rays when they are still concentrated within a sphere so large as Mercury's path round the Sun. By the time they have reached Pluto they are shared out over the surface of a gigantic sphere corresponding to Pluto's huge orbit.

Ways of stopping the spread of heat

Still air in the layers of hay in a hay box will not conduct heat to the outside.

Hot water pipe lagging also contains pockets of still air.

Pockets of still air between blanket fibres lessen conduction losses of the sleeper's body heat.

Thermos flask: Vacuum between walls. No air to move for convection losses. Any radiation reflected by silvered wall.

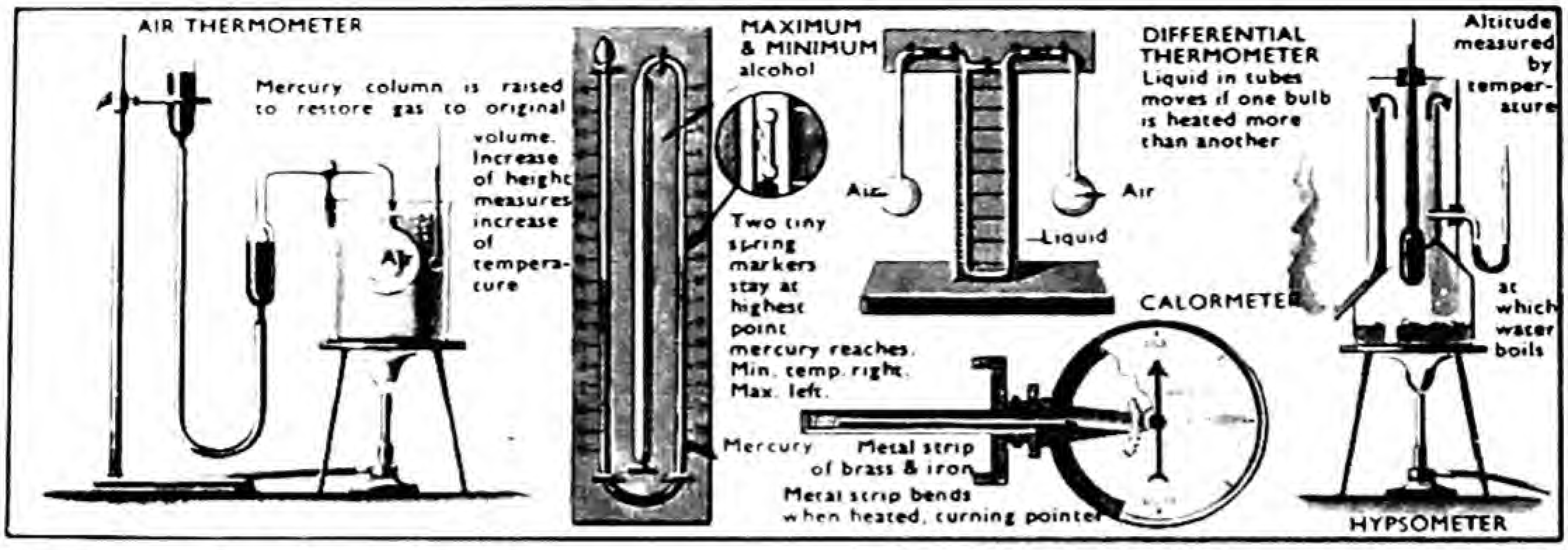
Nearly all materials get bigger when heated and get smaller when cooled. The expansion of a metal is so small that it is measured by a micrometer.

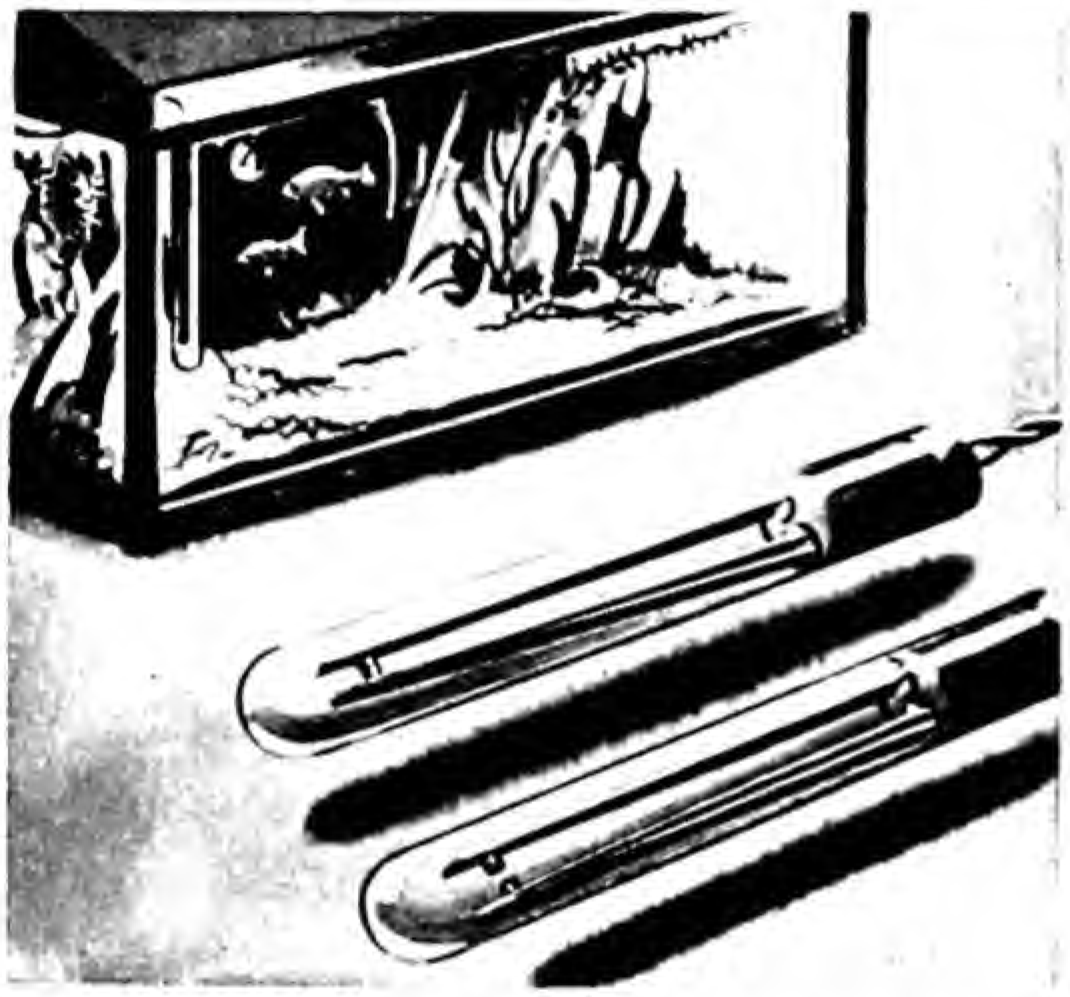
Liquids expand too (everyone knows water spills out of the spout of a kettle if it has been filled right up before heating), and as most liquids expand a lot they are used to measure heat in thermometers.

Strangely enough all gases expand in the same proportion.

A laboratory experiment for measuring the expansion of a hollow metal rod. The micrometer screw is turned to leave a tiny gap ; as the water flowing through the tube makes it hotter the metal expands and closes the gap. Twelve inch rods of different metals expand unequally when raised through the same number of degrees of temperature.

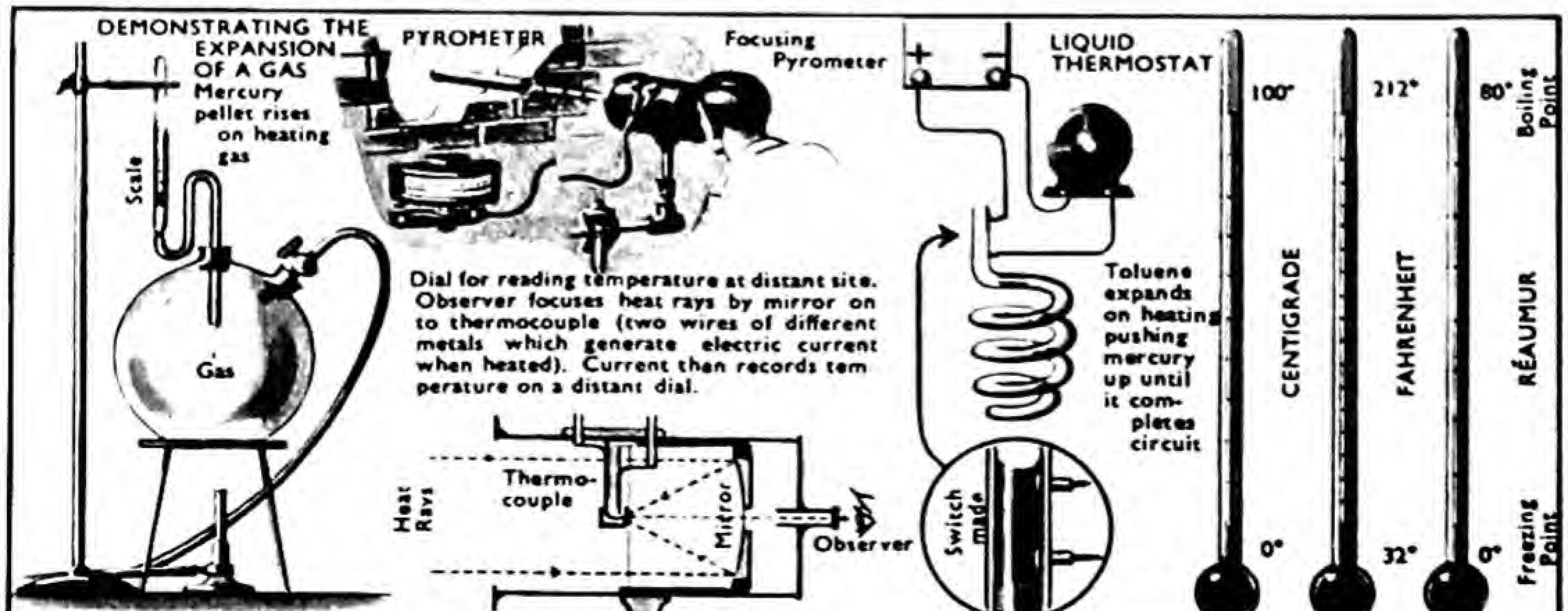
When a ship is being built the steel plates that make up its hull are held firmly together by metal rivets. The overlapping plates have holes bored in them into which red hot rivets are placed The heads of the rivets are then squashed flat and when they contract on cooling they force the plates firmly together (*top left picture*).





Two metals that expand differently when the temperature goes up make the useful thermostat, which switches off electricity at the temperature you want, for instance in a tropical fish tank. In this thermostat one bar is made of two different metals fastened side by side. When heated this bar bends since one of the metals expands more. Thus contact is broken, and the heater switched off.

The fact that metal objects get smaller in size when they are cooled is used in the fitting of liners to the cylinder blocks of motor cars. The liners are first cooled and shrunk in a liquid oxygen machine and then placed in the bores in the cylinder block. When the liners return to normal temperature they expand and fit the bores exactly.



MELTING AND BOILING POINTS

Degrees Centigrade

1755°	Platinum melts
1527°	Iron melts
1360°	Steel melts (variable)
1100°	Glass melts (variable)
1083°	Copper melts
1063°	Gold melts
444°	Sulphur boils
420°	Zinc melts
357°	Mercury boils
338°	Sulphuric Acid boils
327°	Lead melts
287°	Phosphorus boils
230°	Tin melts
176°	Solder melts (variable)
115°	Sulphur melts
100°	Water boils
95°	Sodium melts
80°	Naphthalene melts
62°	Paraffin Wax melts (variable)
60°	Chloroform boils
35°	Ether boils
33°	Butter melts (variable)
0°	Ice melts
-33°	Ammonia boils
-38°	Mercury melts
-183°	Oxygen liquifies
-253°	Hydrogen liquifies
-273°	Absolute Zero

Designing BRIDGES and their Construction

When load comes on to a bridge it has to be resisted by the various members composing the bridge. Metal, timber or any other material has to be placed and shaped to resist the forces in the most economical way. The forces exerted by the load are of two kinds, tension, which means pulling, and compression, which means pushing.

A sheet of paper would not hold any weight placed on one edge. But if the paper is coiled into a cylindrical roll it will support an appreciable weight. (Fig. 1.)

Fig. 1

A piece of rope will not support any weight on top of it but it will support a weight hung on the bottom end – it will resist a tensile force but not a compression force. (Fig. 2.)

Fig. 2

It can be seen, therefore, that materials which cannot support a weight when in one shape, can be made effective by putting them into a different shape or by placing the weight differently.

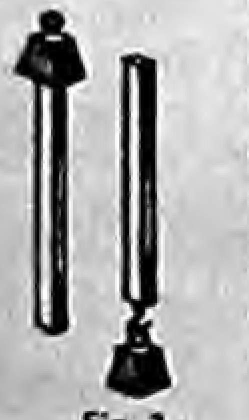


Fig. 3

On the other hand, a steel or wooden rod will support weight at the top or at the bottom, i.e., it will take either tension or compression. (Fig. 3.)

FORCES CAUSING BENDING & SHEAR

It is assumed that steel and concrete and most materials used

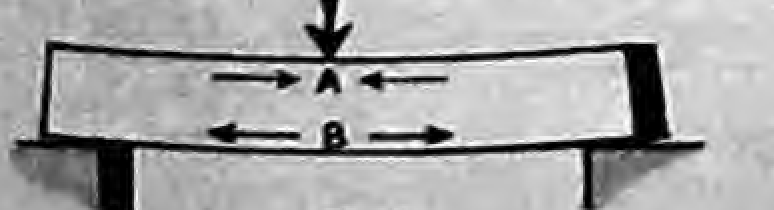
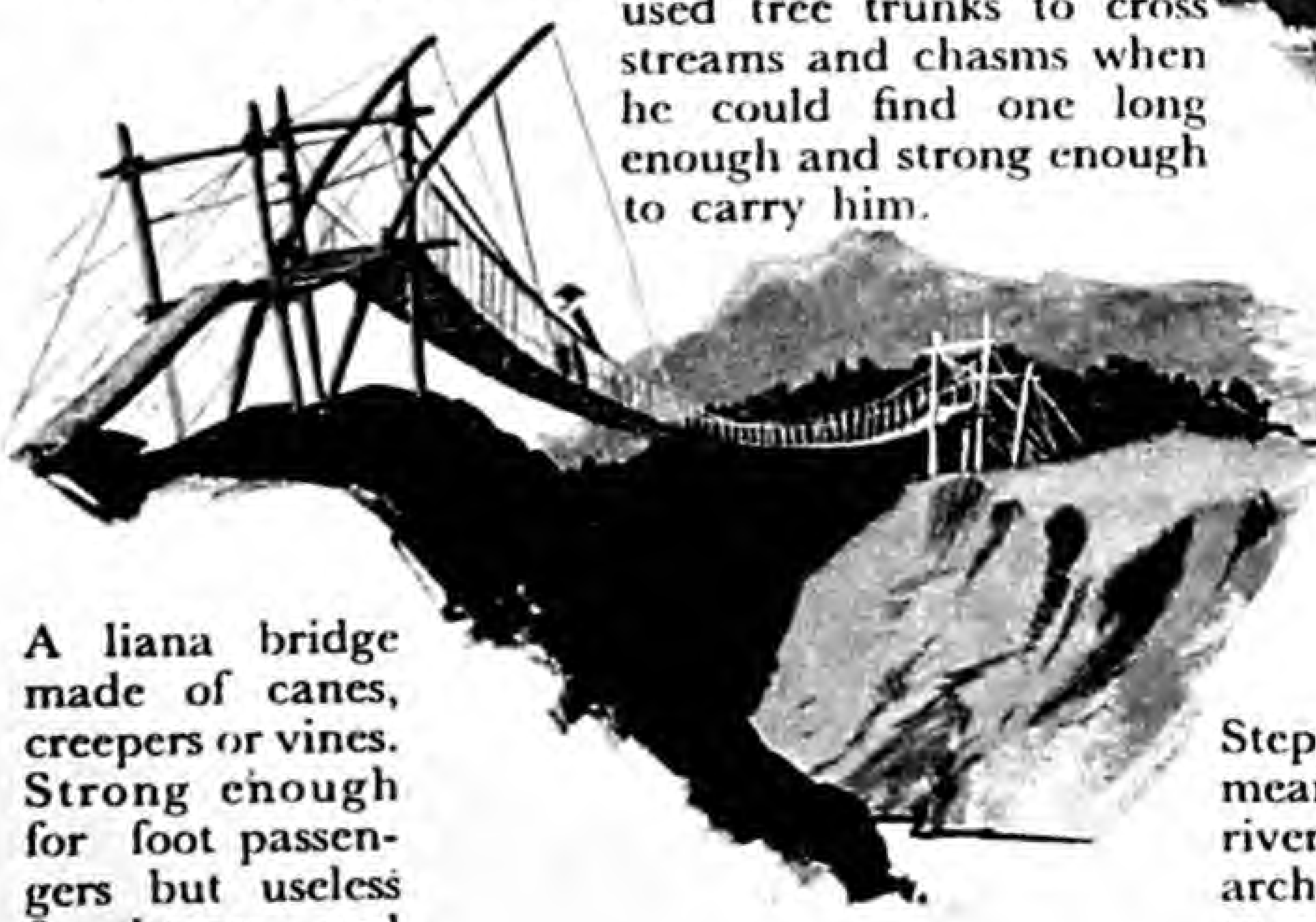


Fig. 4

in engineering behave up to a certain point in the same way as indiarubber. If pulled or bent and

Mountaineers using a primitive form of bridge. Early man probably used tree trunks to cross streams and chasms when he could find one long enough and strong enough to carry him.



A liana bridge made of canes, creepers or vines. Strong enough for foot passengers but useless for horses and vehicles.

Stepping stones as a means of crossing wide rivers were replaced by arched bridges built so as to be supported by the outcrops of stone.

Principles of Design

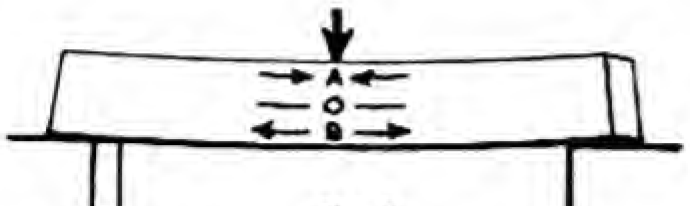


Fig. 5

then released, they go back to their original shape. In Fig. 4 'A' is in a state of compression, 'B' is is in a state of tension.

As these are opposite forces there must be a point where one gives way to the other. It can be seen (Fig. 5) that compression reduces to nothing at point 'o', then tension begins and increases to a maximum to 'B'. At the position where the change-over from tension to compression takes place it must have no stress in it and is called neutral. Throughout the length of a bent beam there must be a neutral layer or axis.

The position of the neutral axis in the depth of a beam depends on its shape and on the material of which it is made. By altering the position of the neutral axis, the intensities of stress at the top and bottom of a beam may be altered. The material in the beam above the neutral axis must be able to resist all the compression caused by the loading and the material below the neutral axis must be able to take all the tension. Once the stresses have been calculated, an engineer can, by adjusting the shape of a beam

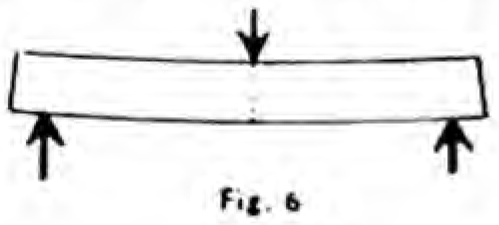
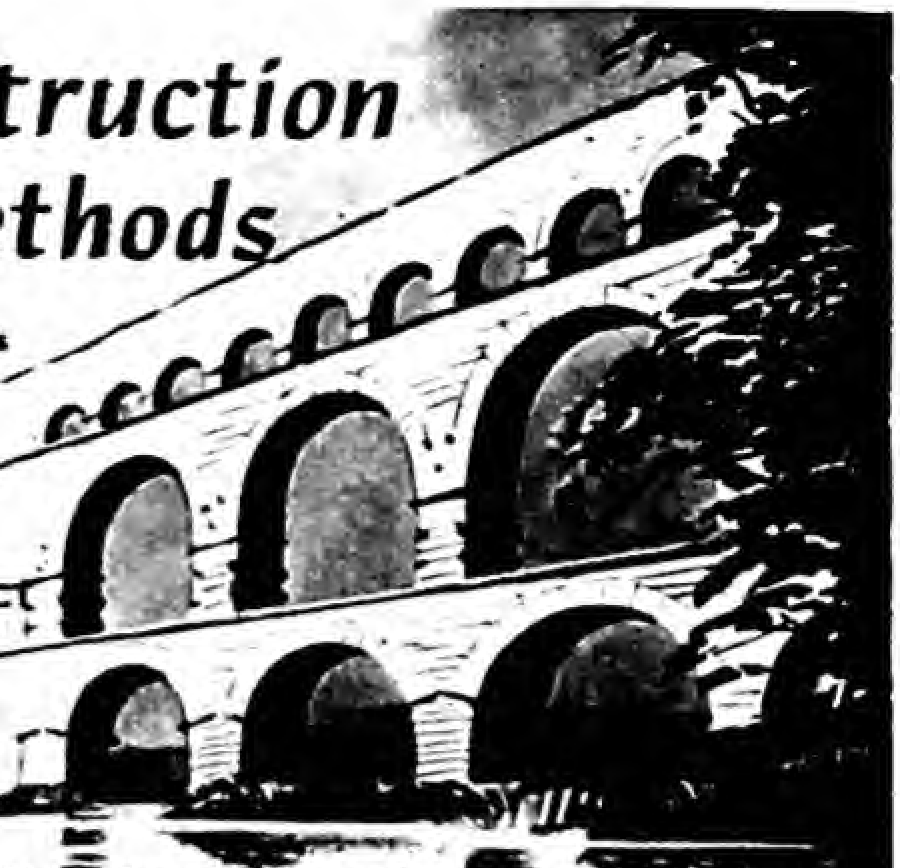


Fig. 6

if required, arrange for a stress, for example, of 6 tons per square inch at the top and of 9 tons at the bottom.

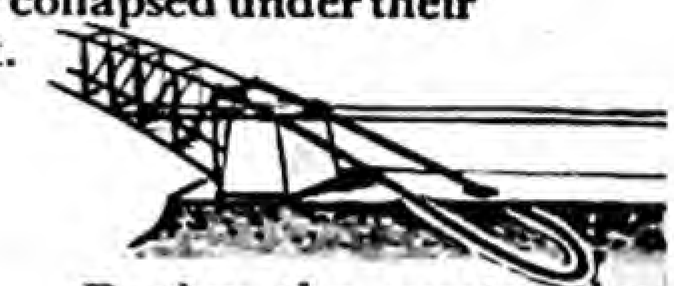
At a certain point the similarity between steel and other building materials and indiarubber ends. This is when the stress is no longer proportionate to the strain, and at this point the steel would no longer revert to the original shape. If more pressure still was applied after this point was

Construction Methods



An arch is made up of wedge-shaped units built round on top of a centering. When the keystone is in position all the parts of the arch transfer the thrust of the weight laid on the arch from one to the other until it reaches the abutments which thus hold the arch in position. The centering can then be removed.

With three tiers of small arches Roman engineers raised the water to the level required. Single arches of stone so high would have collapsed under their own weight.



During the construction of Sydney Harbour Bridge, the supports were tied back by steel cables buried in concrete in U-shaped tunnels.

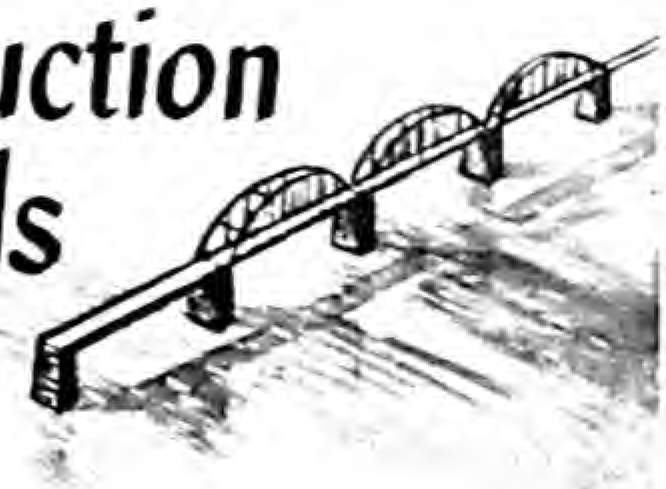
To avoid obstruction of the waterway by a huge centering, the Sydney Harbour Bridge was built outwards from either bank. Special cranes advanced along each half arch to lift the next members into place.

The centre of each arm of a cantilever bridge rests on a support, so that it balances. When the tips of the arms are joined the arms act as connected levers and transfer any load to the tips of the outside arms which are anchored.

Suspension bridges are suspended by cables from an inverted arch formed

by a cable hanging from the tops of lofty towers. The outer towers are anchored by cables buried deep in the rock of the bank. Because the deck can be rocked by high winds, methods of stiffening, usually by making the deck a box section, had to be introduced before this economical method of bridging tremendously long distances with single spans could be used.

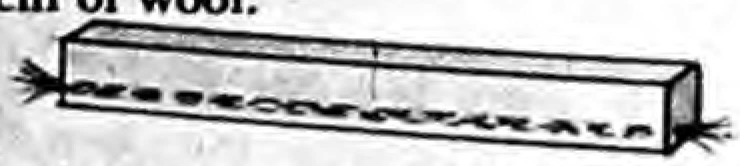
Construction Methods



The simplest form of bridge is the " post and lintel ".

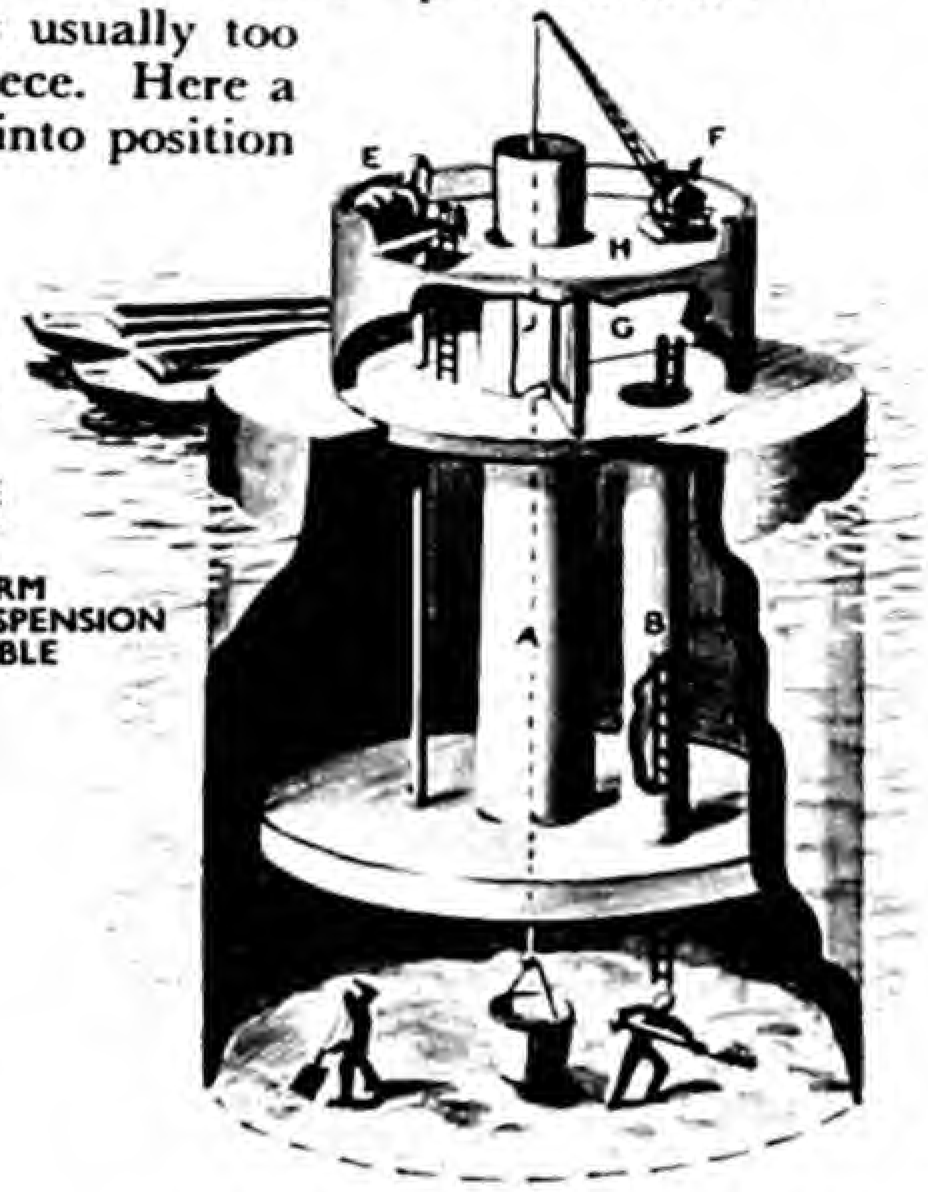
The weight of the span (" lintel ") is usually too great to be lifted into place in one piece. Here a 500-ton floating crane is able to float into position for an easy lift.

The travelling pulley carries wire to the pylon top as if winding a skein of wool.



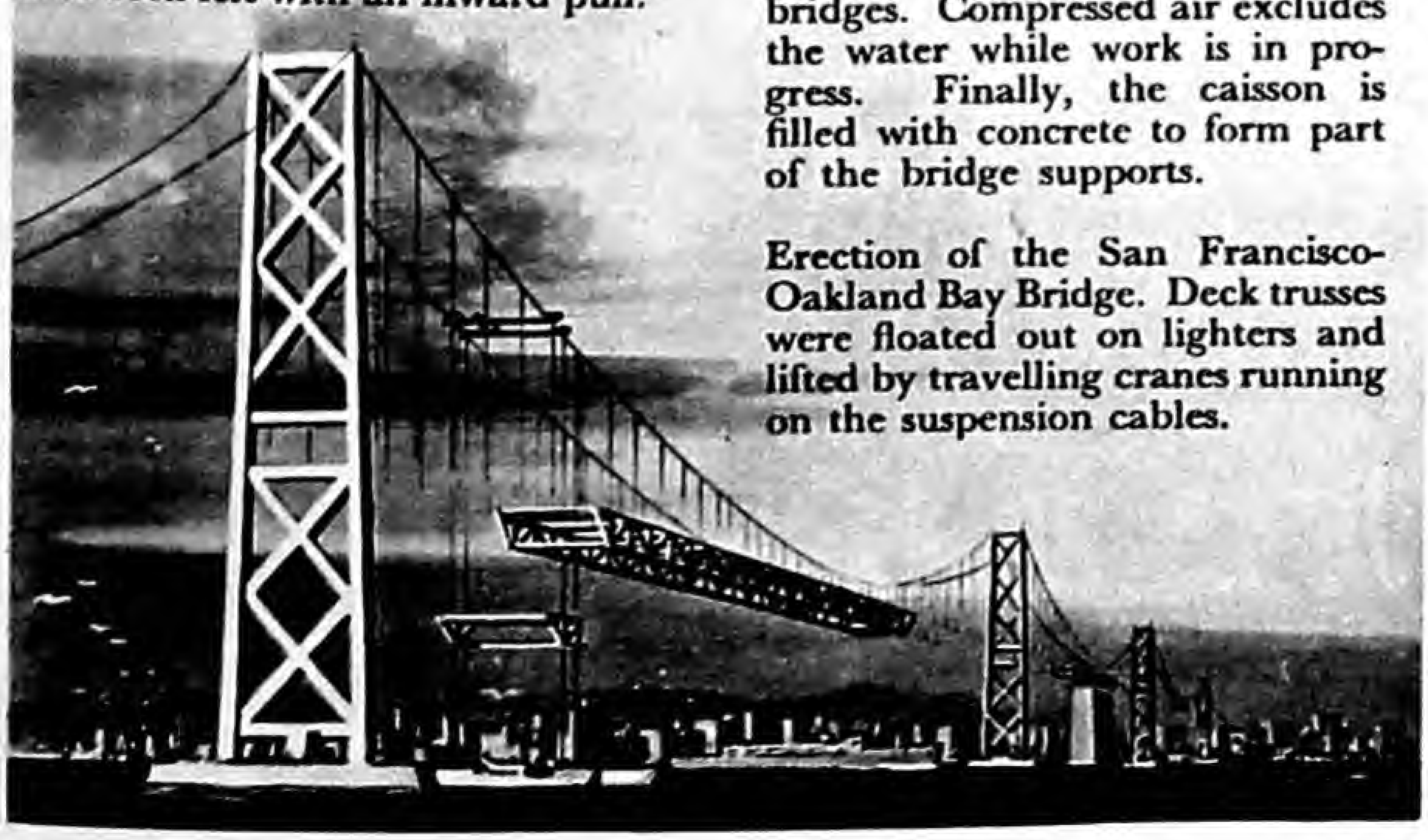
Tension put on wires *before* concrete sets round them means the lower part of pre-stressed concrete beam has a " built in " resistance to tension.

Under load beam can counteract extra tension at 'B' because wires have been left with an inward pull.



A. Bucket shaft. B. Man shaft. C. Air supply. D. Compressed air chamber. E. Compressors. F. Crane. G. Air lock chamber. H. Working platform.

The working of a steel caisson used in excavating and building the under-water foundations of bridges. Compressed air excludes the water while work is in progress. Finally, the caisson is filled with concrete to form part of the bridge supports.



Erection of the San Francisco-Oakland Bay Bridge. Deck trusses were floated out on lighters and lifted by travelling cranes running on the suspension cables.

Design

reached, the steel would start to

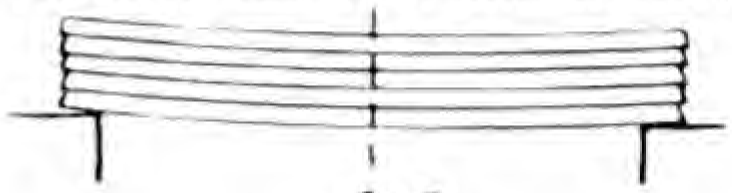


Fig. 7

break. For safety, the stress permitted must be well within the elastic limit and, in building a structure such as a bridge, this safe load would be worked out in each case by engineers.

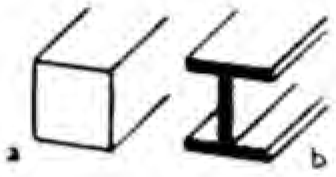


Fig. 8

A beam that is bent by carrying a load is subject to compression and tension

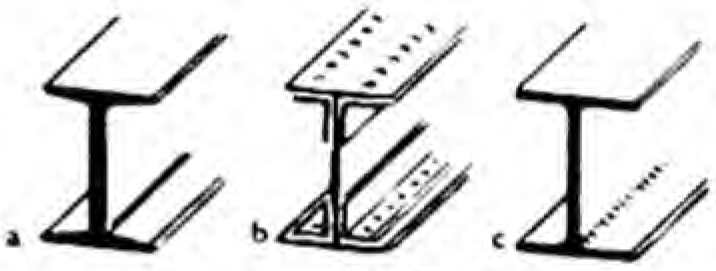


Fig. 9

but there are also acting in it other forces called shear forces.

A beam that is bent will assume the shape shown in Fig. 6. If the beam is thought of as if it was cut into layers, as shown in Fig. 7, the layers would be found to slip over each other. It will be seen that the slipping is most at the ends of the beam. It is the stresses that tend to cause this slipping over effect that we called " shear " stresses.

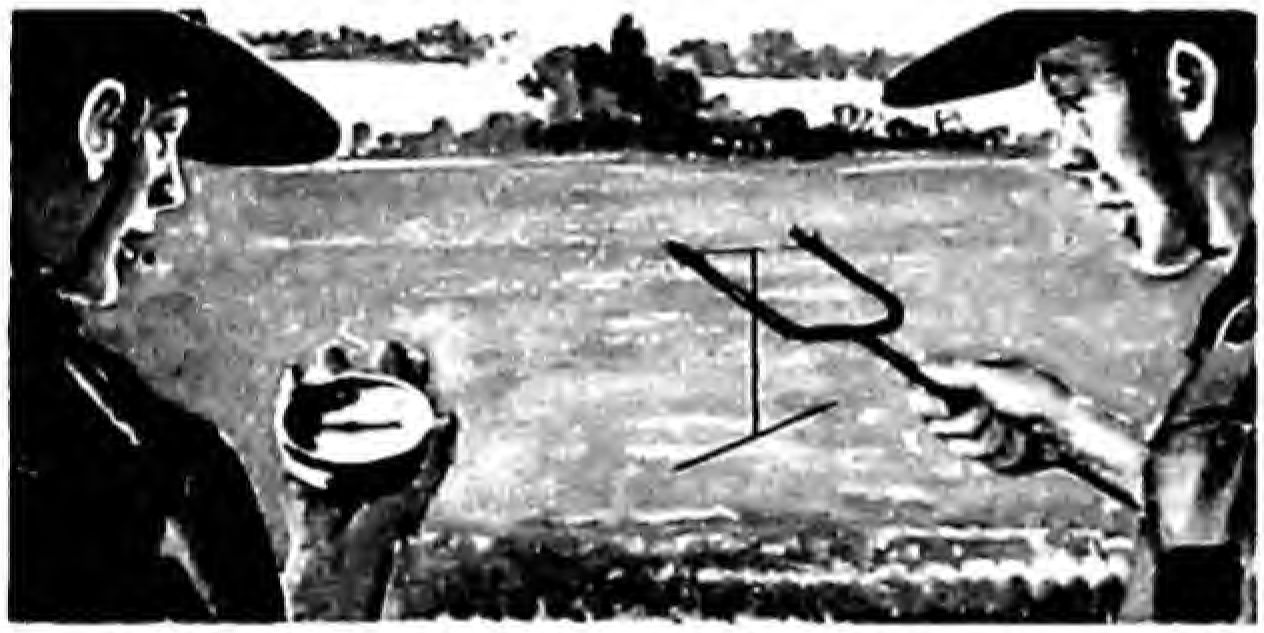
The maximum shear stresses are along a vertical line running through the length of a beam. Maximum bending stresses are along the top (compression) and bottom (tension) faces of the beam.

A steel beam of rectangular section could be used (Fig. 8(*a*)). But the same result would be more economically obtained by using less materials as in Fig. 8(*b*). A more exact shape is Fig. 9(*a*), which, of course, is the familiar rolled steel joist. A shape may be built up of angles and plates and held together by rivets (Fig. 9(*b*)) or of plates only and welded together (Fig. 9(*c*)).

THE MYSTERIOUS POWER OF MAGNETISM

The magnet has been known since ancient times. The Saxons found pieces of iron ore naturally magnetised and discovered that hung up they always pointed N. and S. So they called them lodestones, stones that show the way. Proper compasses were made by the 12th century (*see pages* 178-179), but it was a long time before seamen realised that the magnetic needle at the same time dips towards the Poles. In other words, the earth's magnetic field is not just a

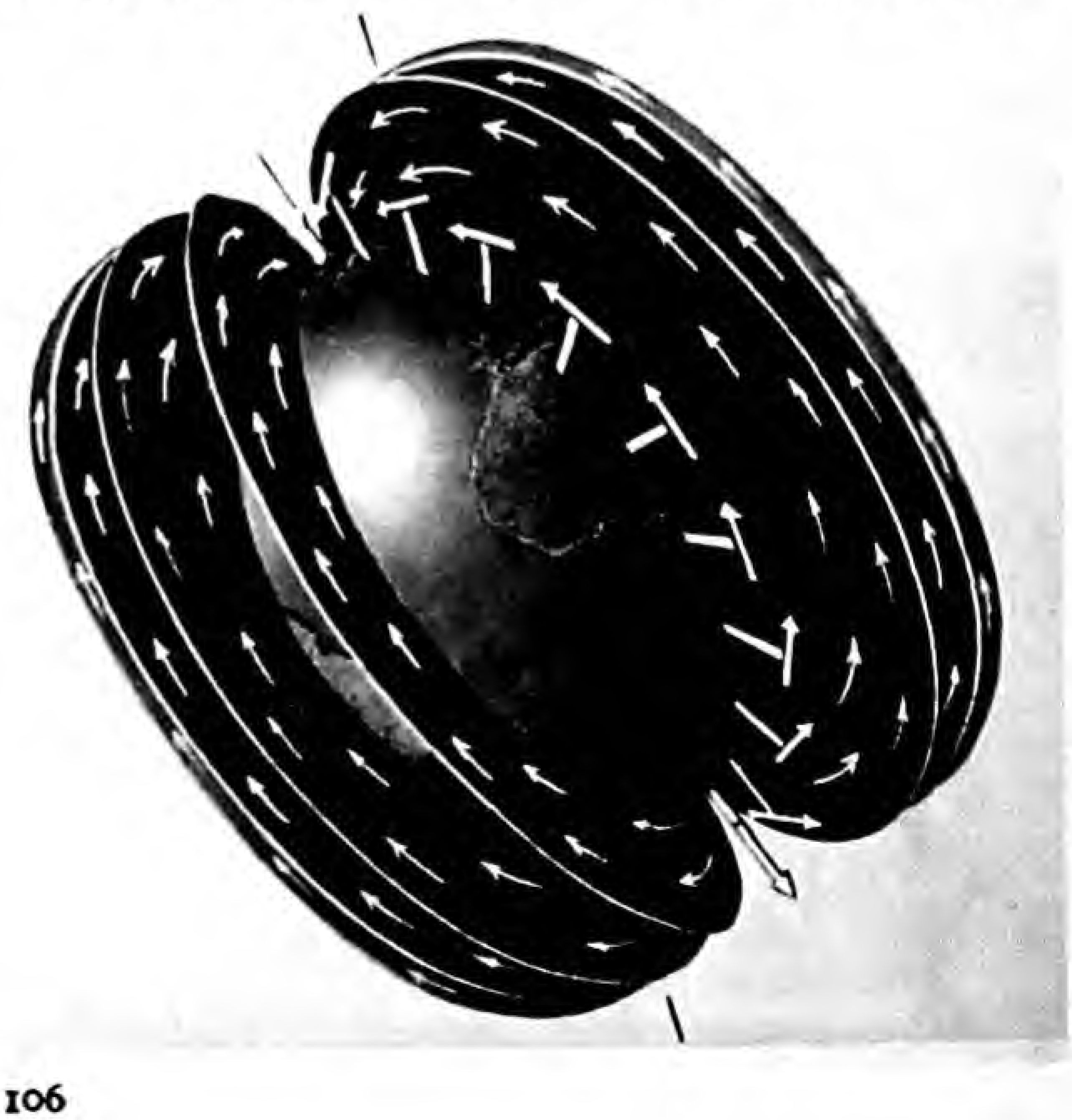
Many early peoples discovered that pieces of iron ore would hang N. and S. because of their natural magnetism.



Exact measuring of the magnetic " dip " needs delicate instruments usually carried in surveying aircraft.

The magnetic field of the earth is a continuous field extending out into space and enveloping the earth like a shell. The compass held flat against the surface of the earth always points north. But a freely suspended " dip compass " points as the arrow shows when it is taken to different parts of the earth. It points straight down to the ground at the North Magnetic Pole and straight up into the air at the South Magnetic Pole.

The geographical North and South Poles lie on the imaginary " axle " about which the earth spins. The compass needle points to the magnetic North Pole which is some distance away from the true North Pole.



skin, it extends in all directions, just like the magnetic field of any magnet, as you will discover if you do the experiments with iron filings that the early physicists did (see below).

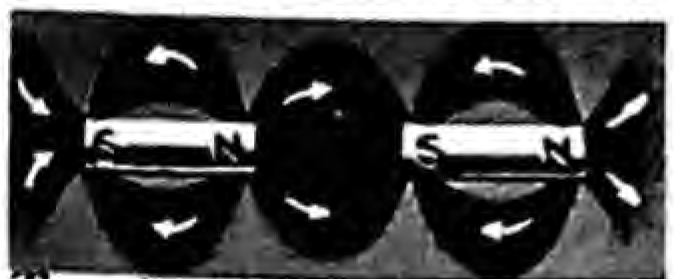
The usual small ship compass has several compass needles fixed under the compass card which swings round. Its North point is marked on it.

No matter how much a rolling ship puts the compass housing over at an angle the compass card rolls easily in the gimbals either way and remains steadily horizontal. While it is level with the earth's surface the compass card will swing to register the horizontal magnetic field but if tilted its swings might partly be registering the dip of the magnetic field.

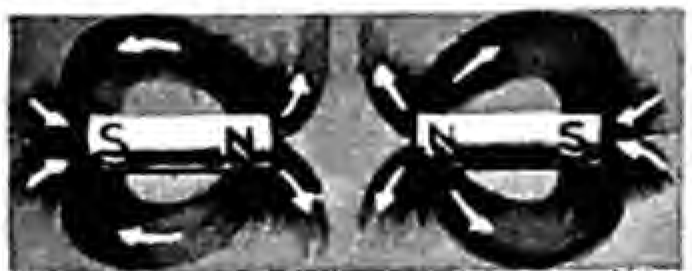
Ships compasses must be kept exactly level with the earth's surface or they will be affected by the vertical magnetic field. So they are hung in gimbals—tin rings that swing inside each other and stay steady no matter how the ship rolls or pitches.

Invisible Magnetism makes its own Picture

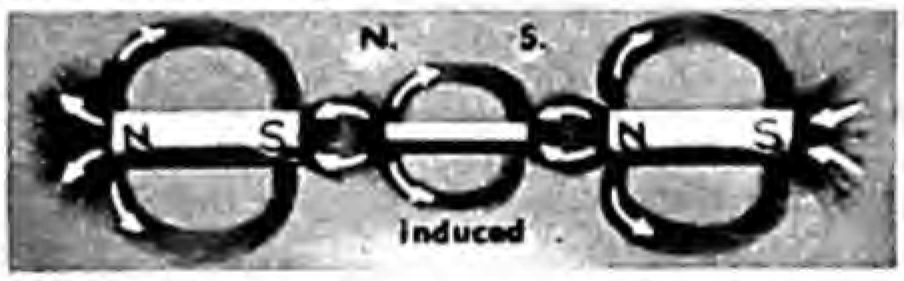
The lines of force form a field all around a magnet. This can be proved by making iron filing charts at different angles. The lines of force also continue inside the magnet.



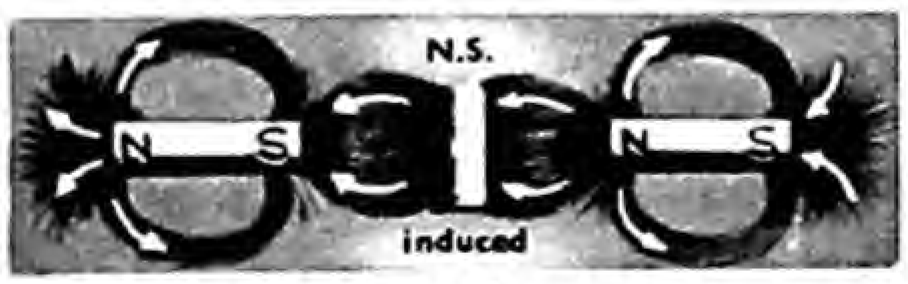
Two bar magnets with unlike poles together.

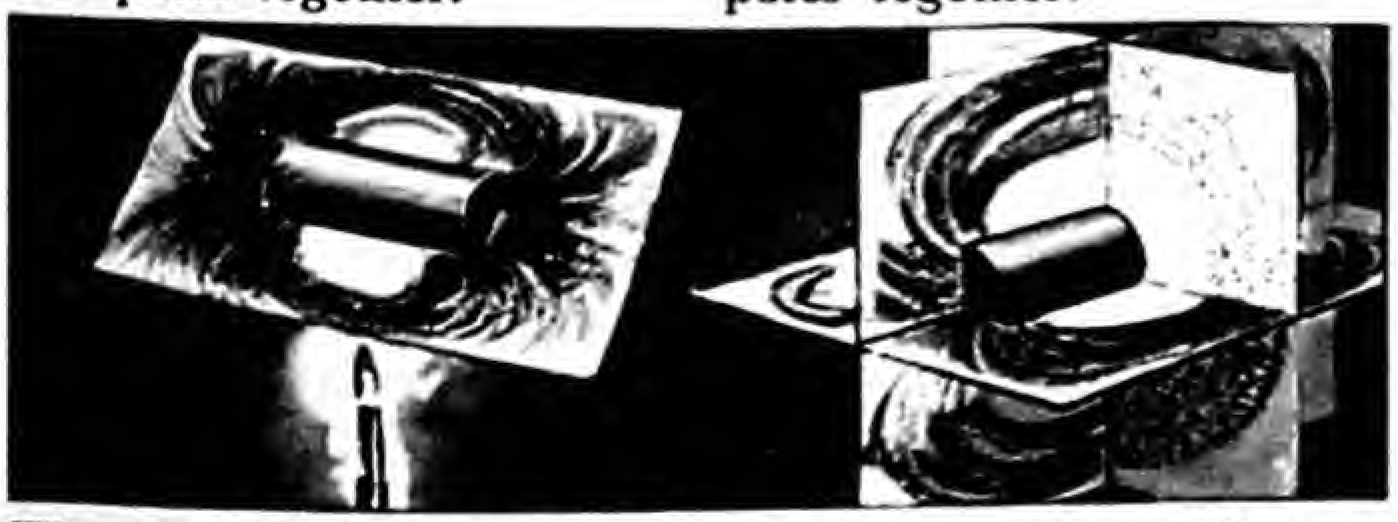


Two bar magnets with like poles together.

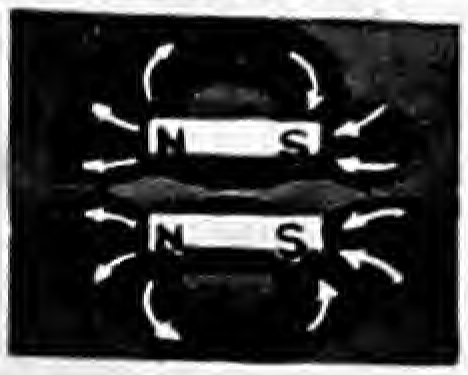


A bar of soft iron between magnets is magnetised by induction ; polarity depends on the direction of the lines of force, which seem to find iron easier to pass through than air.



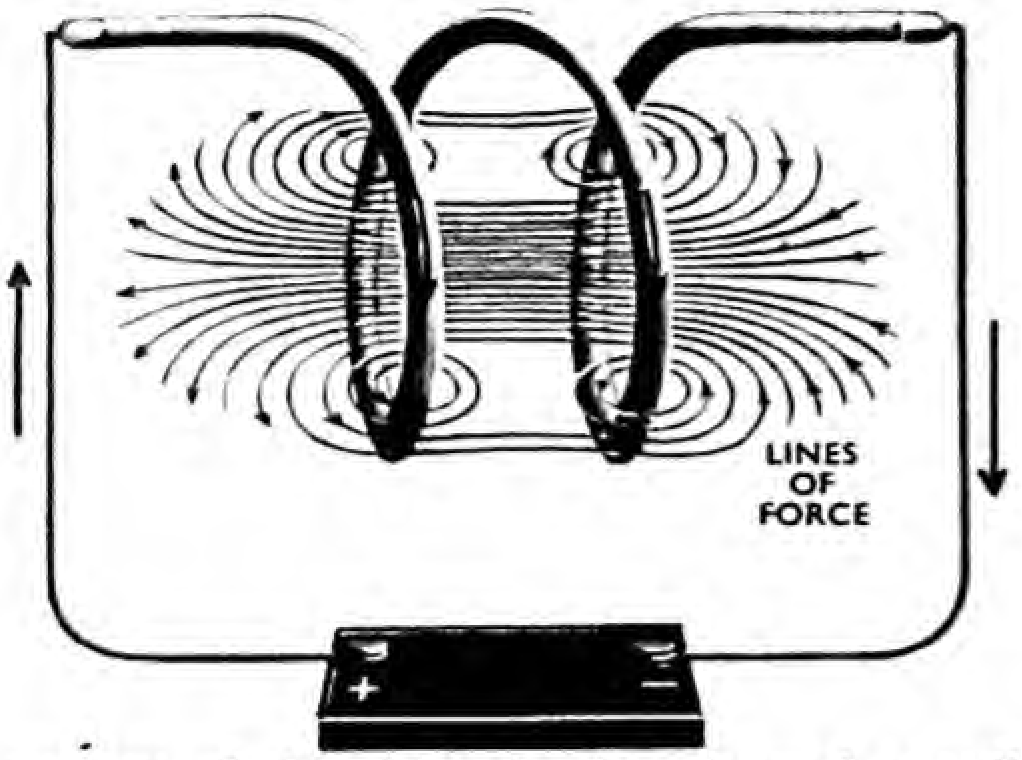


The waxed paper fits over the bar magnet, iron filings are dusted on to it and after the paper has been gently tapped, take up positions showing the magnetic effect of the lines of force. The paper is warmed so that the iron filings are fixed in the wax.



The magnetic fields of magnets side by side.

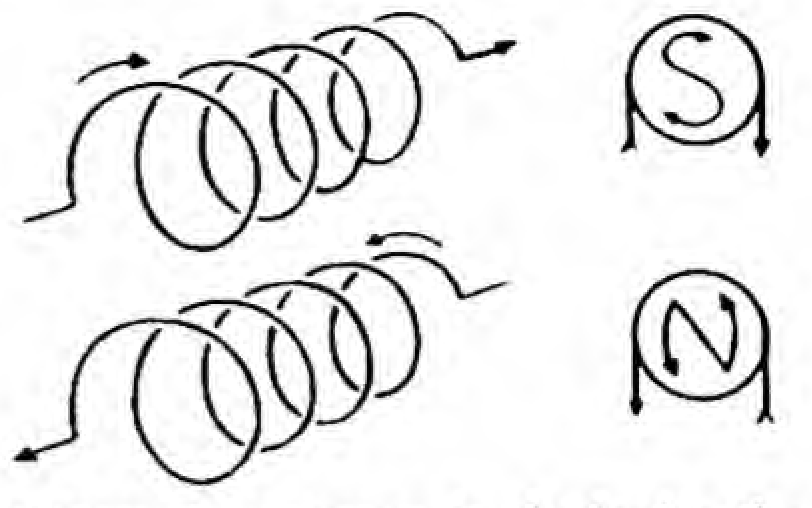
Right: Lines of force round a wire through which an electric current is flowing.



A current of electricity flowing through a coil of wire has the effect of making a magnetic field very similar to that of a bar magnet.

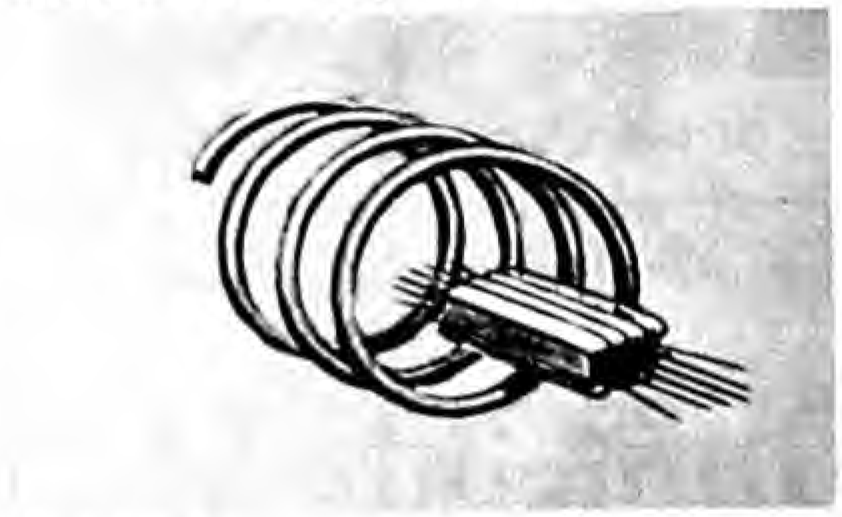
Only iron and steel cobalt, nickel and *some* alloys of manganese can be permanently magnetised, but copper acquires a field when it is a coiled wire carrying an electric current. An astonishing thing happens when an ordinary coil of copper wire in circuit with an ammeter but with no battery has a magnet pushed into it—an electric current flows in the coil. When the magnet is taken out again a current flows in the opposite direction. This is how electricity is generated mechanically. In practice we turn a coil between the ends of a horseshoe magnet, as you see below. Current is induced whenever, as it turns, the coil cuts across a greater or lesser number of lines of force.

See also THE ELECTRICAL ENGINEERS USE OF ELECTRICITY

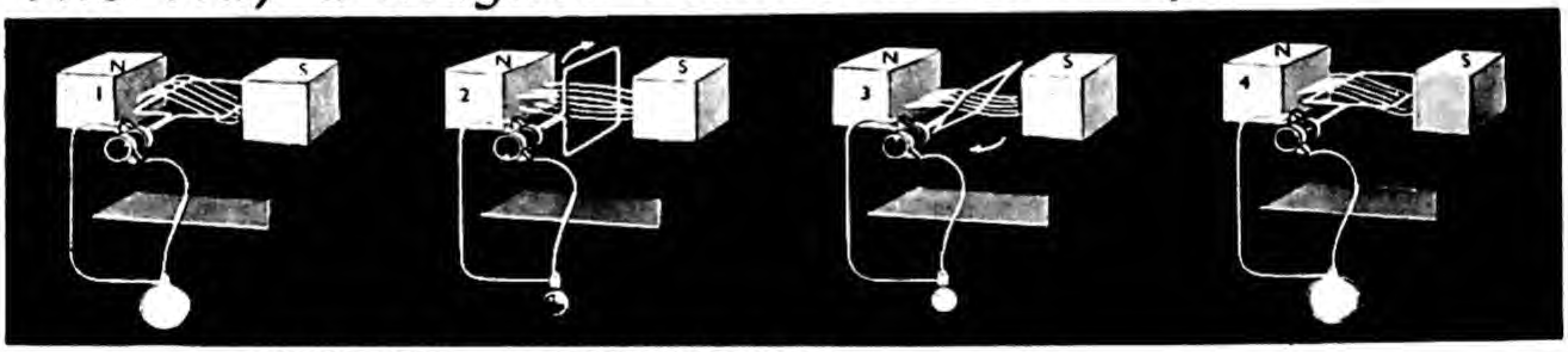


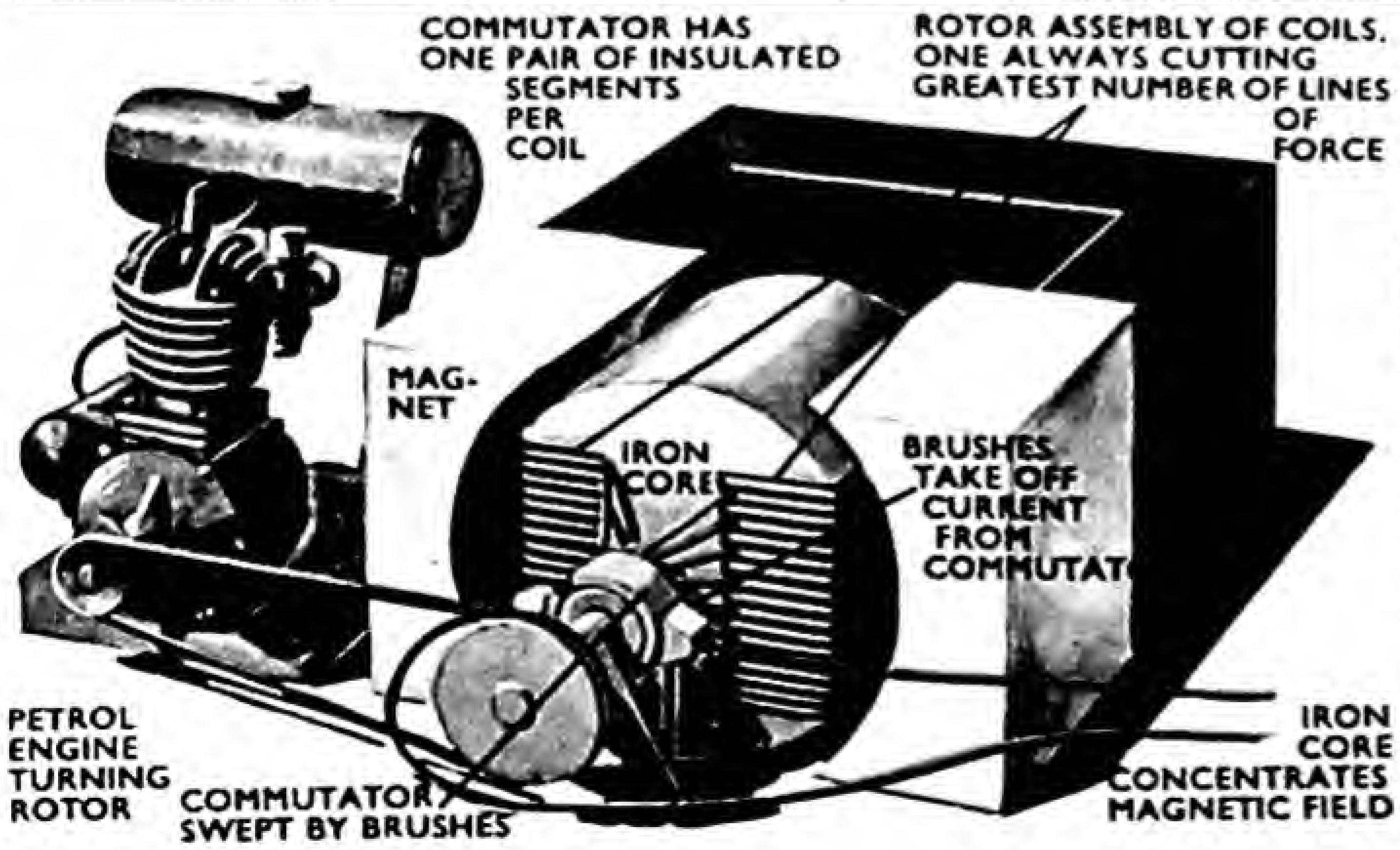
When the current is clockwise the end you are looking at is the South Pole. When it is anti-clockwise you are looking at the North Pole. The small diagram with the letters S and N show an easy way to remember this rule.

Just the movement of the magnet makes electricity in the coil.



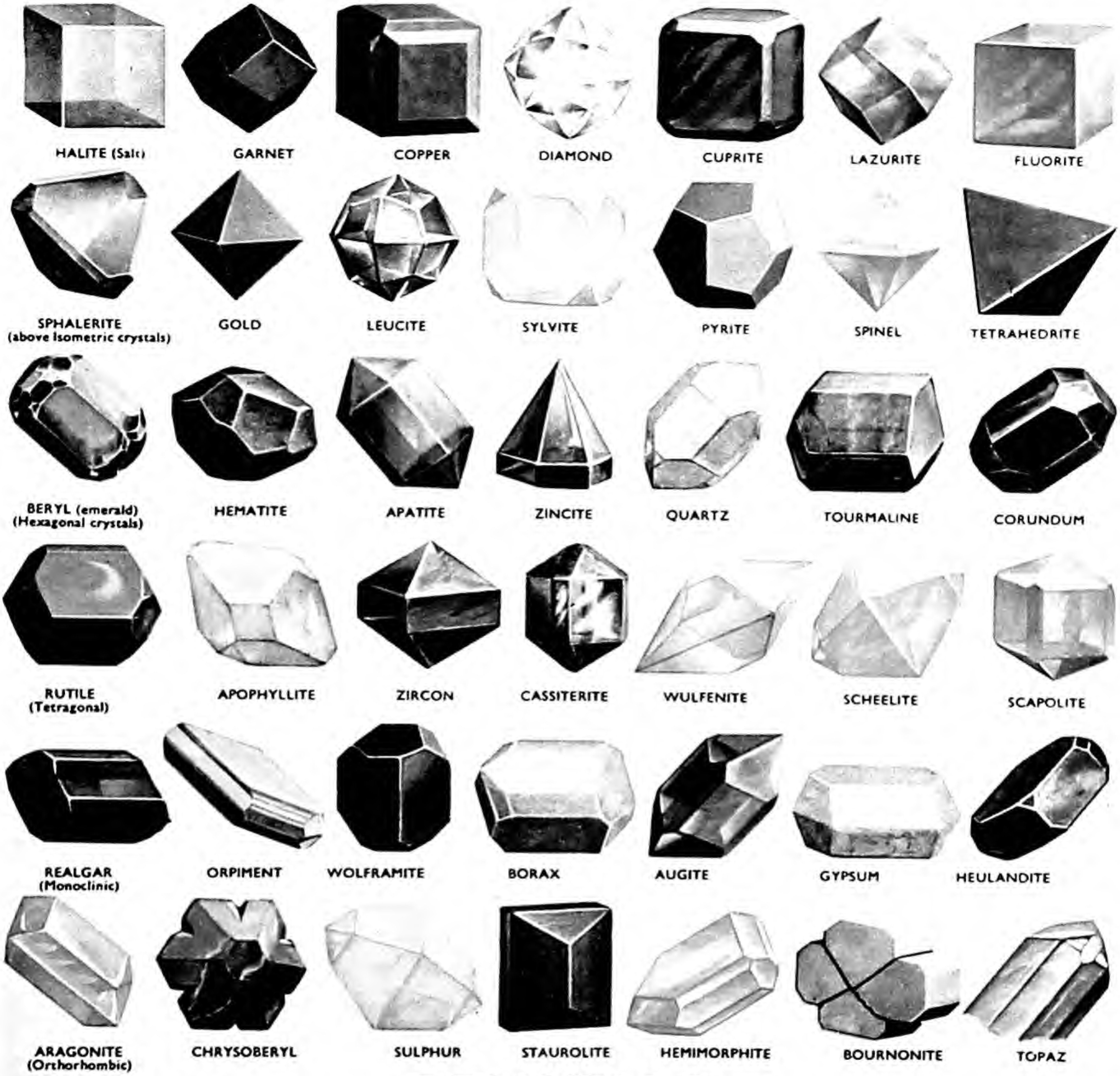
The Way a Magnet Makes Electricity

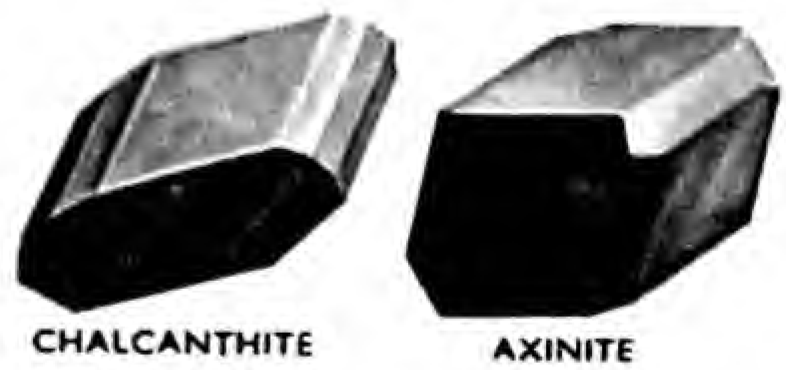




1. Since many lines of force are being cut as the coil turns, current is induced and the lamp lights. 2. No lines of force are being cut for the coil is moving along them, so the lamp goes out. 3. The coil is starting to cut a few lines of force again so the current is small but increasing. But the coil has turned over so the current flow is backwards. 4. Coil cutting many lines again so the current flow is big. The coil is still upside down to its first position so flow is still in the opposite direction, i.e. alternating current is produced.

(*Left*) A simple motor-driven alternating current generator. In practice they are more complicated than this.

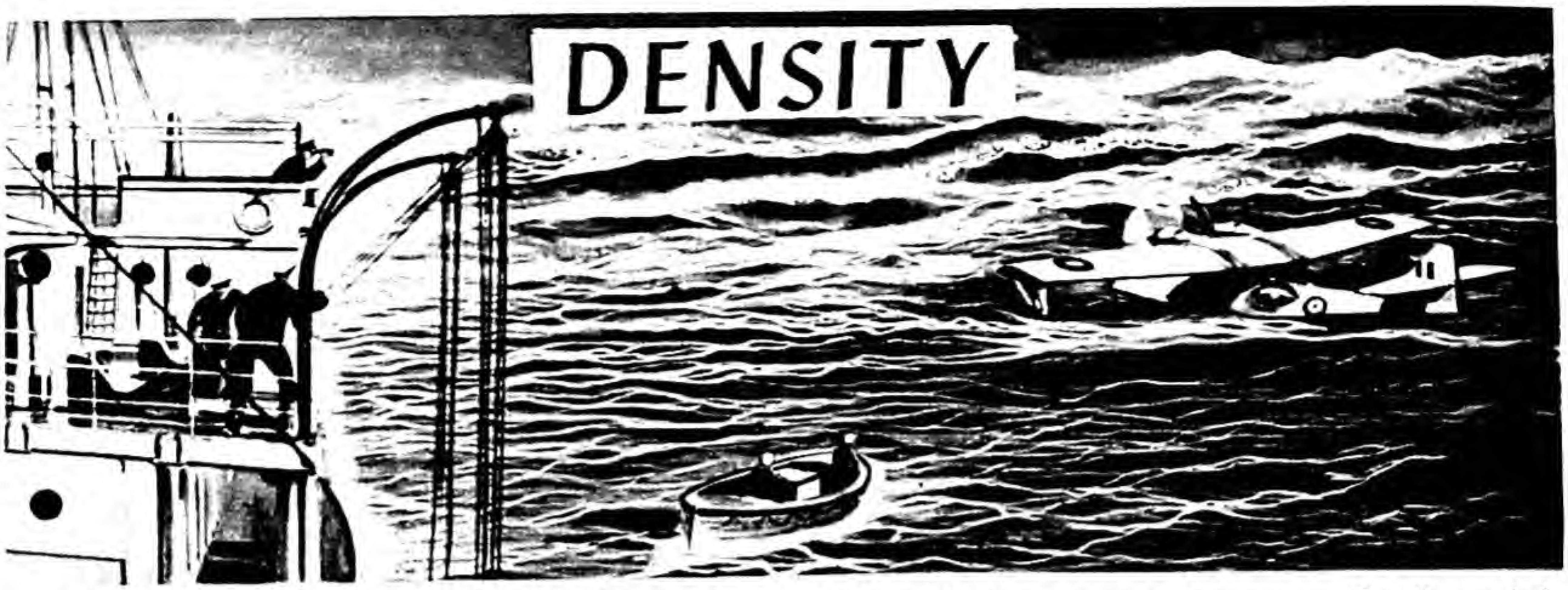




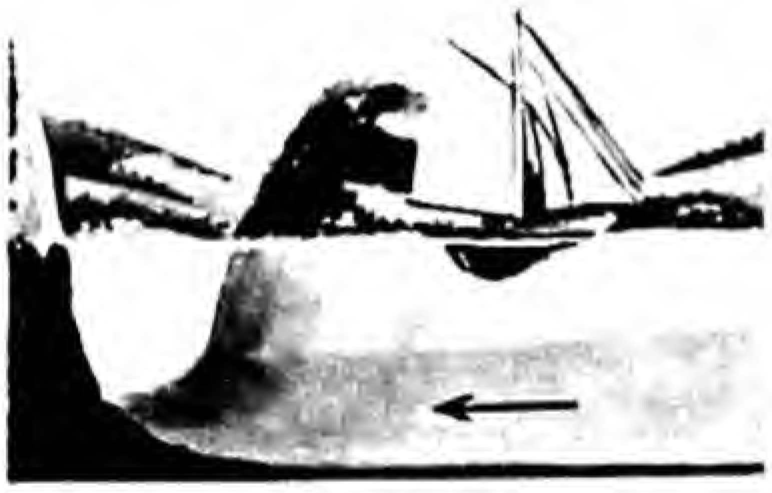
CRYSTALS

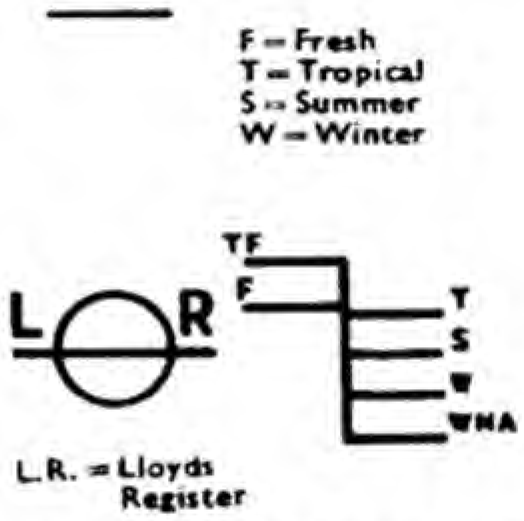
The atoms or molecules of many substances can become grouped into regular patterns. The visible effect of this is the making of a crystal. Crystals of a particular substance can be recognised because they have a constant shape. This shape can be described in geometrical terms. Crystals found in nature are not so perfectly formed as are those on this page.

DENSITY



Oil, pumped onto the sea by the rescue ship, helped its lifeboat to reach the crashed plane. The oil floated on the surface because its density was less than that of the water—a pint of oil weighs less than a pint of water—so the oil goes to the top. The oil *smoothed* the sea because of its viscosity.

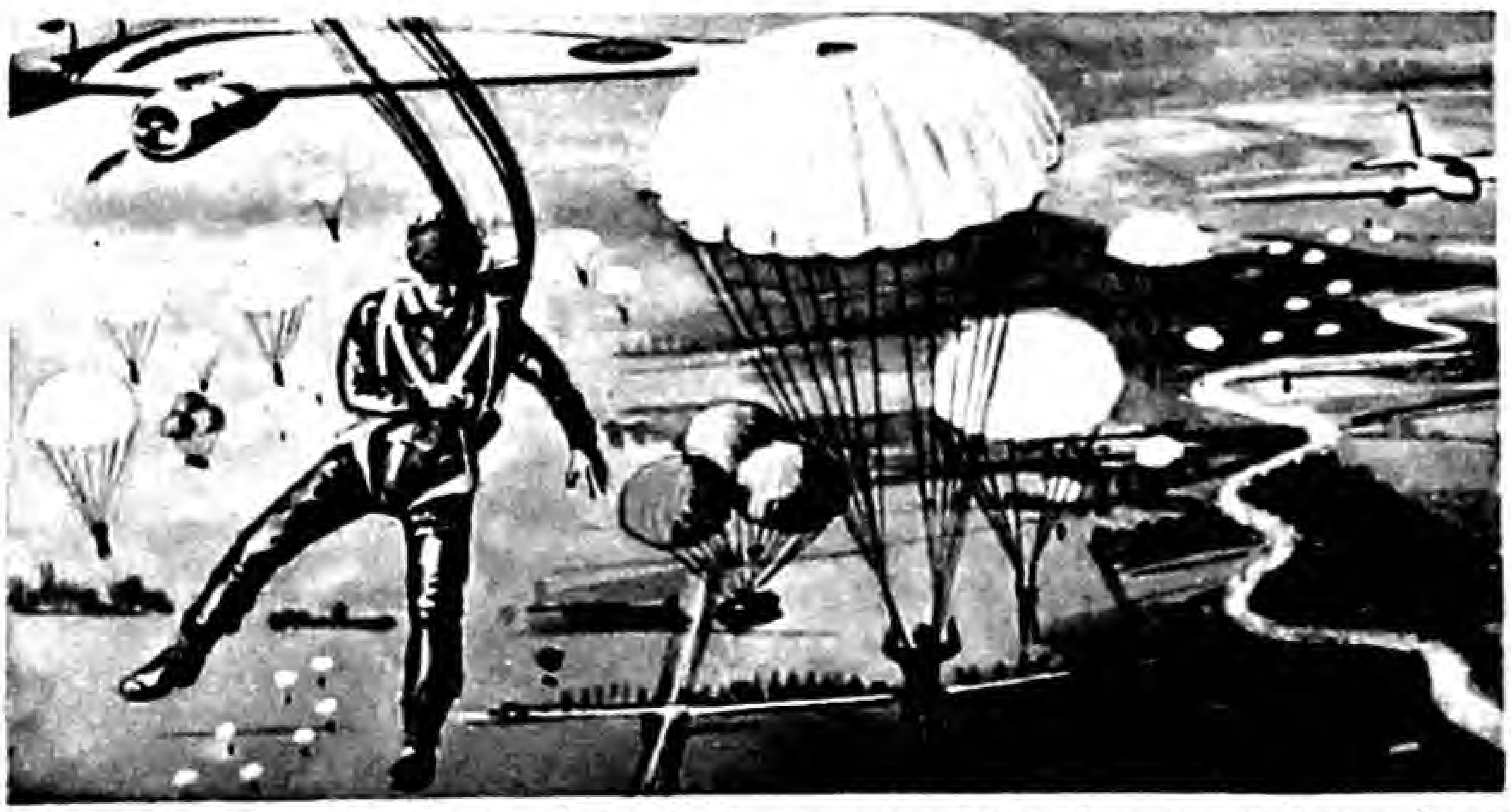




T.F. or Tropical Fresh Water, is much less dense because it is fresh and warm. Ships ride lower in it and must carry less.

When the tide comes up an estuary (*left*) the salt sea water, being denser, pushes in under the less dense fresh water coming from the river. So the river water rides out to sea on top of the salt water. The density of water is also affected by temperature. Ships' loading marks (*right*) have various alternatives. W.N.A. means Winter North Atlantic, where the water is extra dense because it is very salt and cold. Ships can thus float better in it and carry heavier loads.

To measure the density of a liquid a hydrometer is floated in it. The less dense the liquid, the deeper the hydrometer must settle to displace its own weight of liquid. Because the density of sulphuric acid alters with the strength of the acid, hydrometers are used for testing batteries. *Left*, an ordinary hydrometer float; *right*, a battery hydrometer with the float in it.



Since air, like other gases, has density, a parachute, because it has a large spread, can slow down the speed at which a load falls.

Solids vary in density, too. The big pillar is made of sandstone, the smaller one of marble. Both are the same weight so the smaller pillar has the greater density of the two.

PROTECTIVE CLOTHING

Many workers wear special clothing to protect themselves. Some, like the fire-fighter, do so to guard against the possible hazards of their jobs; others, like the soldier in arctic uniform or the high flying pilot, to enable them to operate in extreme conditions of temperature or pressure.

An asbestos suit protects fire fighters from burns, because asbestos is a bad conductor of heat.

Repairing acid - carrying pipes, men wear rubber capes and helmets.

Anti-G suit of pilot applies pressure to abdomen, thighs and legs to prevent blood pooling when there are changes in acceleration.

Surgeon's mask filters off bacteria as he breathes out and non-porous gloves and clothes prevent bacteria lodging in them.

Mask protects lungs of chemical workers from deadly vapours.

Steel mask protects face of welder from oxy-acetylene sparks and tinted mica visor reduces glare.

Protection against extreme cold. Soldier's outer garment keeps out wind; light weight inner clothes (string vest etc.) keep inside air still to avoid loss of heat by conduction.

Nike guided missile uses nitric acid as fuel, so crewmen refuelling it wear rubberised suits to protect them against acid burns.

Radiologist wears lead jacket to guard against X-rays.

Metal fireguard protects driver of bulldozer from flames so that drum of nitro-glycerine can be exploded to put out oil well fire.

Radioactive dust in this worker's protective suit must not be allowed to fall on the floor, so he is brought to the changing room on a trolley.

Using geiger counter on shoes to check presence of radioactive dust.

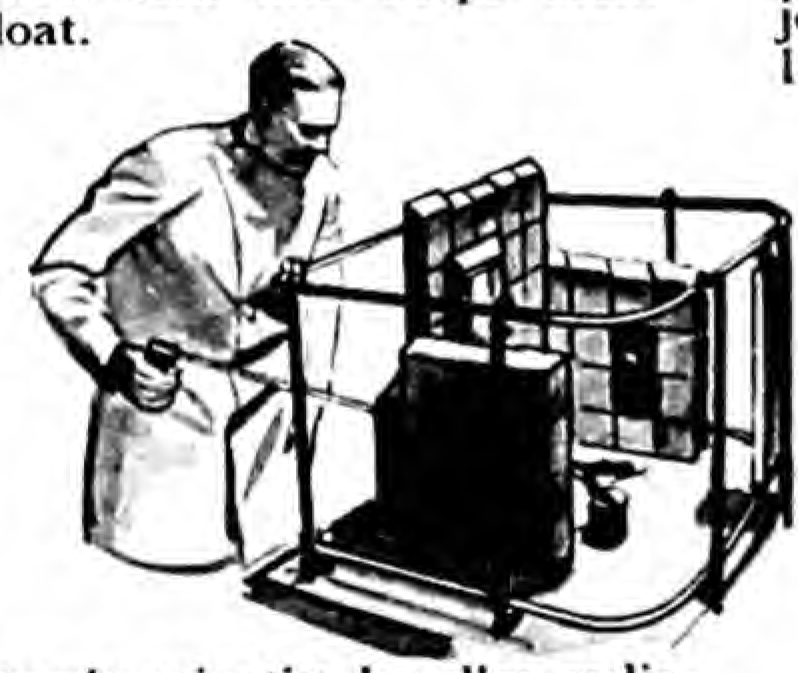
Filling a bottle with radioactive chemicals from behind glass screen.

Suit for protection in area of heavy radiation.

Air between skins of immersion suit insulates ship survivors from death-dealing cold of winter seas and keeps them afloat.

Atomic station engineers use long-reach tools to repair pipe line joints through which radio active liquids have been pumped.

Atomic worker, opening drum of radium ore, wears respirator as protection against radon gas liberated by ore.



Atomic scientist handles radioactive material with long tools behind barrier of lead bricks.

Mosquito net in tropics keeps out dangerous mosquitos.

Anti-flash gear protects naval gunner from cordite burns.

Deadly smoke gases go right through respirator, so fireman carries own oxygen.

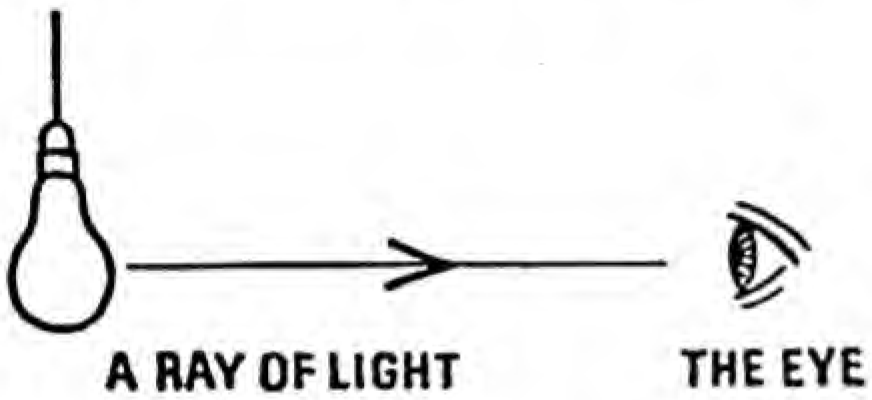
Air between double walls of Everest two-man tent and insulated floor protects climbers from frostbite.

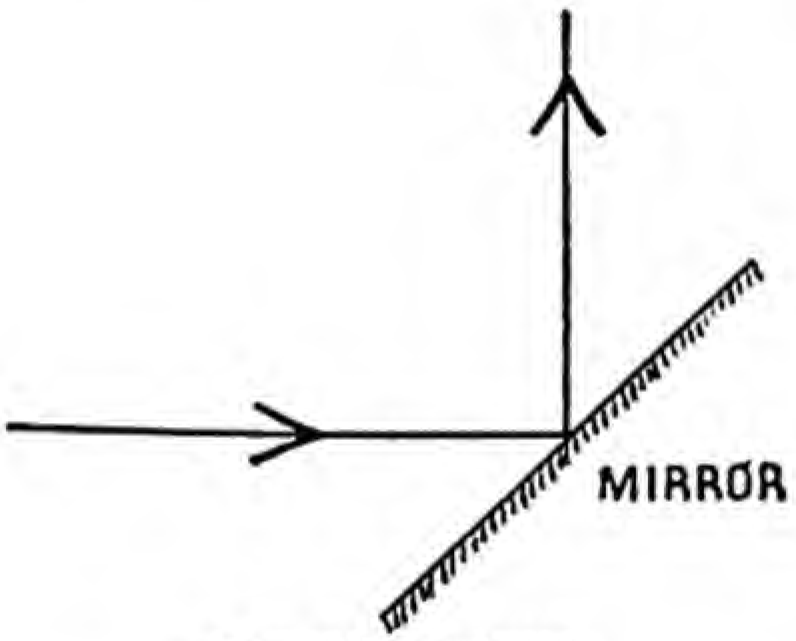
Tropical tent also has double walls to keep pocket of cool air circulating.

Temperate climate tent has single wall.

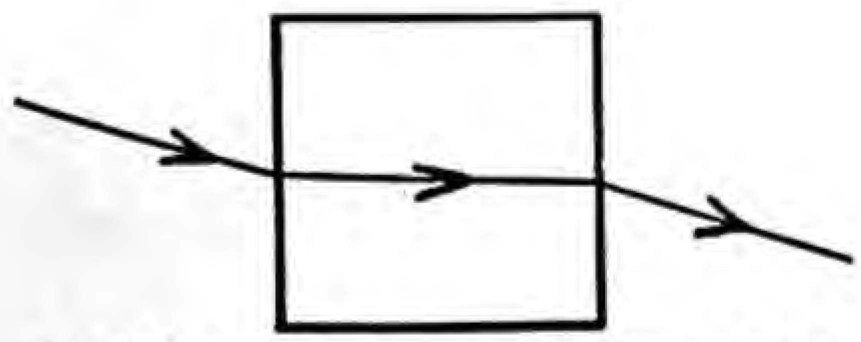
SHADOWS, MIRRORS AND LENSES

LIGHT. Light is a form of energy in the form of waves, travelling at 186,000 miles per second through space, almost as rapidly through air, and somewhat slower through transparent liquids and solids. In Physics, we usually consider very narrow slices of light waves, known as rays of light. We represent them as a straight line with an arrow-head, pointing away from the source of light. Rays of light travel in straight lines unless they are *reflected* at the surface of another substance or are *refracted* on passing into another substance.



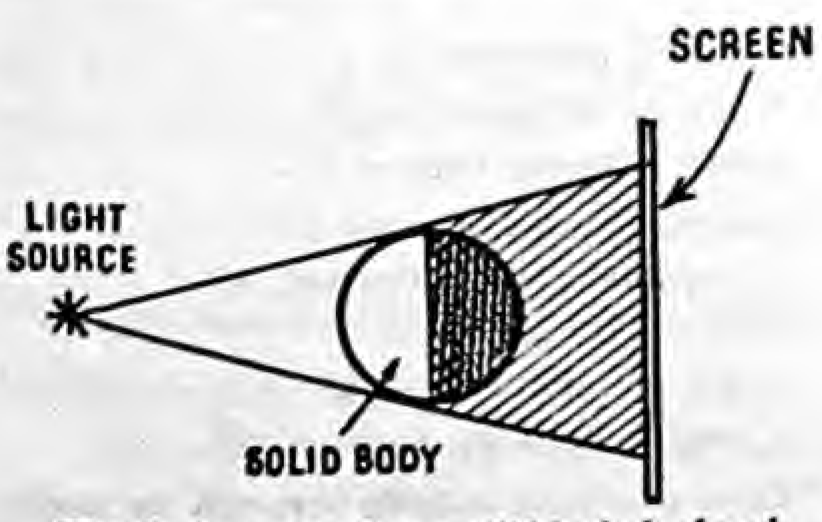


A ray of light reflected.



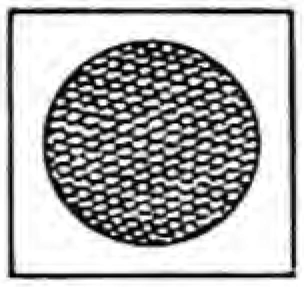
A ray of light refracted on passing through a block of glass.

A SHADOW. When a solid body is placed between a source of light and a screen, certain areas are shielded from light by the solid body. Such areas are shadows.

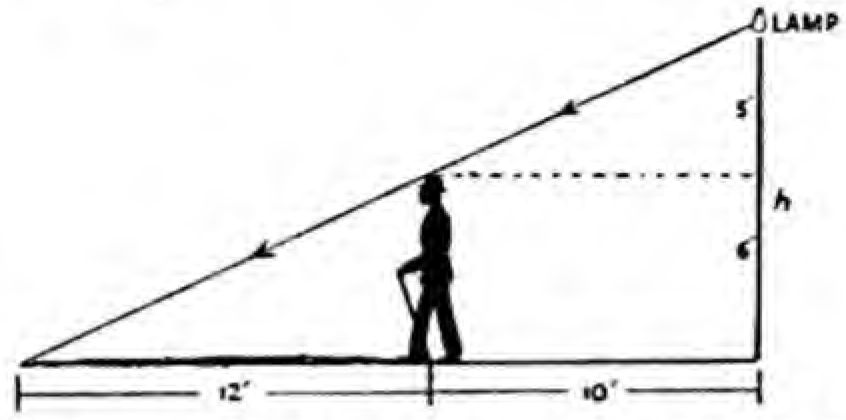


The shadow cast when a solid body is placed between a tiny source of light and a screen.

The appearance on the screen.

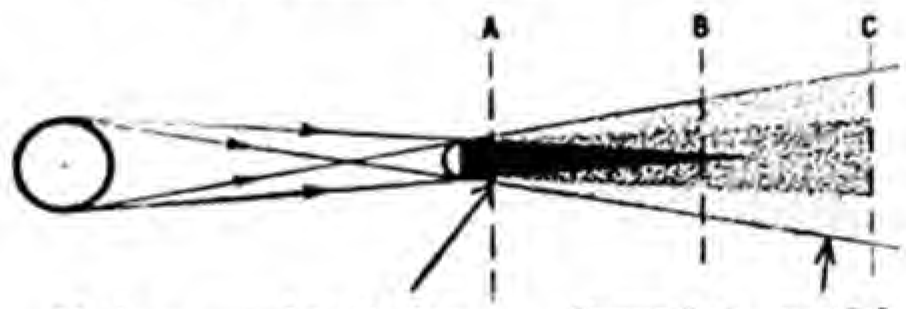


Calculation: The shadow of a man, 6 ft. tall, cast by a street lamp 10 feet behind him is 12 ft. long. How far above the ground is the lamp?



The ray of light shown above falls 6 ft. vertically in 12 ft. horizontally. In 10 ft. it will fall $\frac{10}{12} \times 6 = 5$ ft. Thus the lamp is 5 feet taller than the man, i.e. 11 feet.

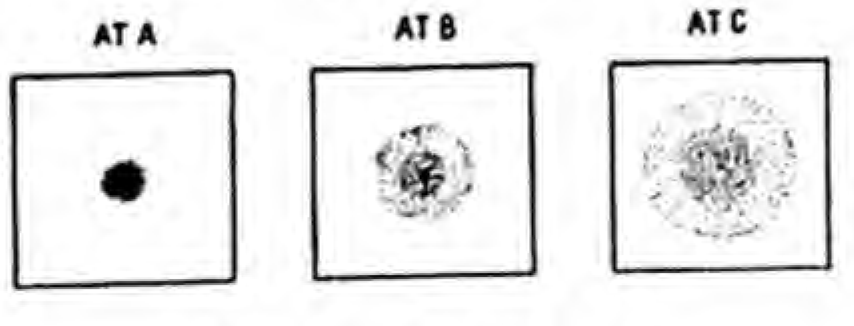
The shadow cast by a large luminous source, e.g. a "Silverlight" electric lamp, which is bright all over



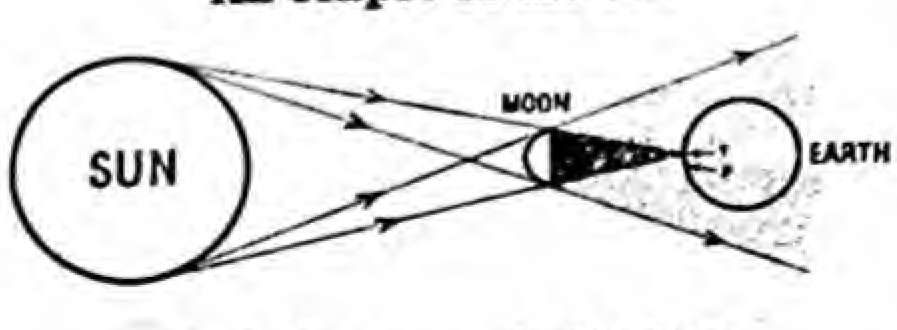
Umbra, complete shadow.

Penumbra, partial shadow; very deep near umbra, becoming fainter towards edges.

Effect on a screen.



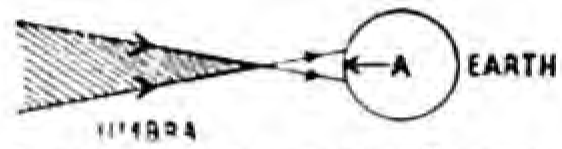
An eclipse of the sun



Total eclipse seen at T

Partial eclipse seen at P

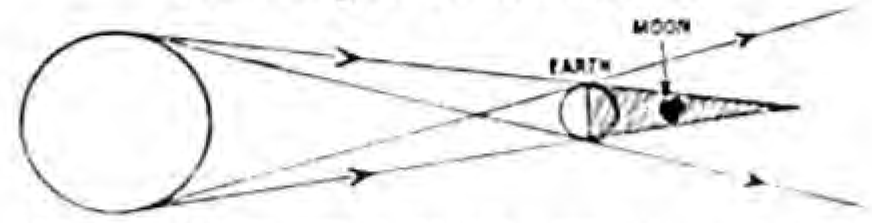
Silhouette of moon just covering sun. Flames around sun can be seen.



Annular eclipse occasionally seen (at A).

Silhouette of moon not quite covering sun.

An eclipse of the moon



INTENSITY OF LIGHT. The intensity of a source of light is usually given as so many "candle-power". There was, at one time, a special type of candle, giving exactly one candle-power, to serve as a standard. It was replaced by a very special type of lamp burning a special fuel, pentane, and giving exactly 10 candle-power; and later by a specially made electric lamp. The latest standard is a hole 1 sq. cm. in area through which can be seen the inside of a small furnace containing the metal platinum at its melting point. The intensity is about 60 candle-power. A new unit has been introduced, and the light given out by the hole in the furnace is exactly 60 "candelas".

The intensity of illumination on a surface is
(a) directly proportional to the candle-power of the lamp, e.g. 100 c.p. gives 100 times the intensity of illumination as 1 candle-power.
(b) inversely proportional to the square of the distance from the lamp, e.g. twice the distance, a quarter the intensity of illumination, three times the distance, one ninth, five times the distance, one twenty-fifth the illumination, and so on.

One foot-candle is the intensity of illumination when a lamp of 1 candle-power is placed 1 foot from the surface.

Example 1: A lamp of 100 candle-power is placed 3 feet above a table. What is the intensity of illumination?

1 c.p. 1 ft. away gives 1 foot-candle.

100 c.p. 1 ft. away gives 100 foot-candles.

100 c.p. 3 ft. away gives $\frac{100}{3 \times 3}$ foot-candle.

$= 11\frac{1}{9}$ foot-candles.

Example 2: For sewing, an intensity of 20 foot-candles is recommended. How far from the work should an electric lamp of 180 candle-power be placed in order to provide this intensity of illumination? Let the distance bed feet.

The intensity due to a lamp of 180 c.p. 1 foot away = 180 foot-candles.

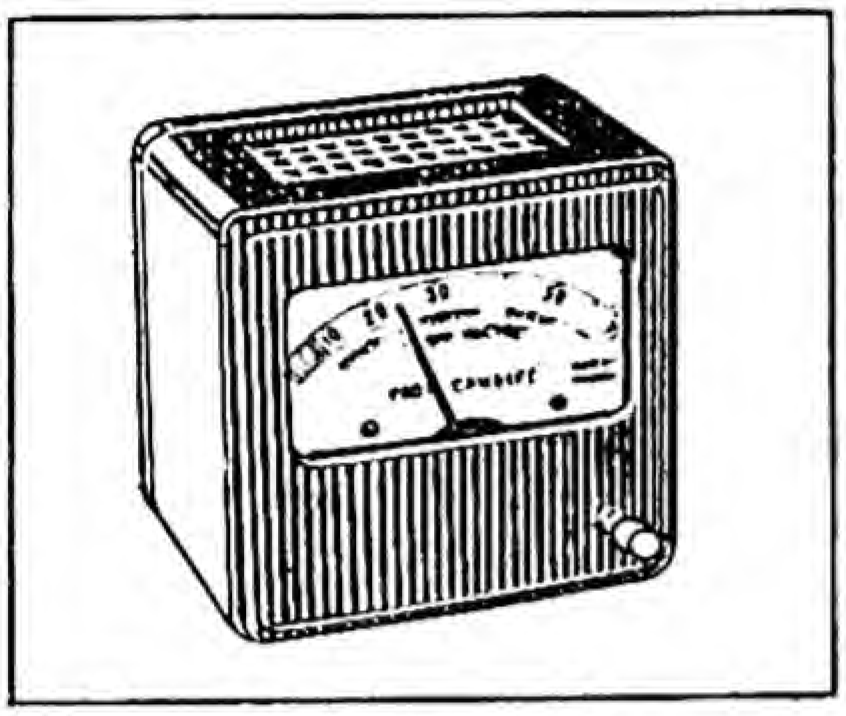
The intensity due to a lamp of 180 c.p. d feet away $= \frac{180}{d^2}$ foot-candles.

This is 20 foot-candles, so $20 = \frac{180}{d^2}$

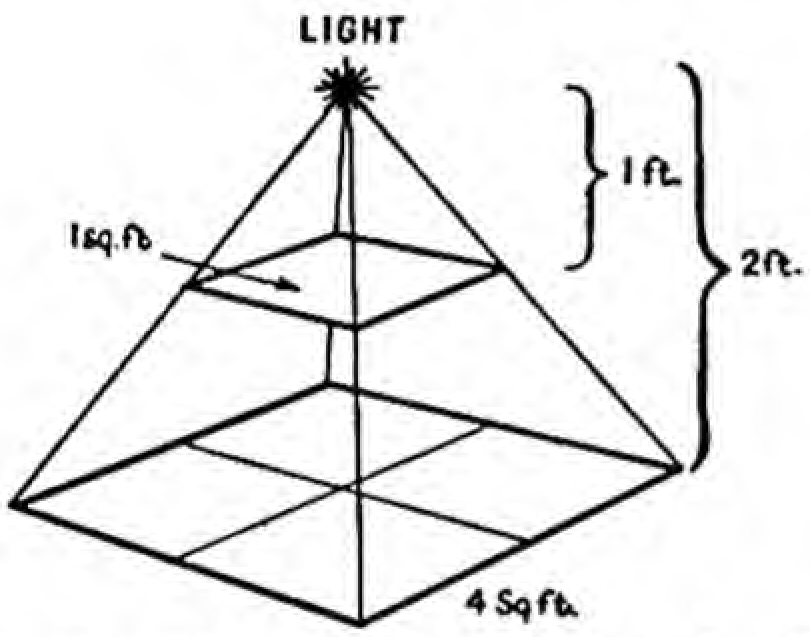
$\therefore 20\,d^2 = 180 \quad \therefore d^2 = 9 \quad \therefore d = 3.$

The lamp should be 3 feet away from the work.

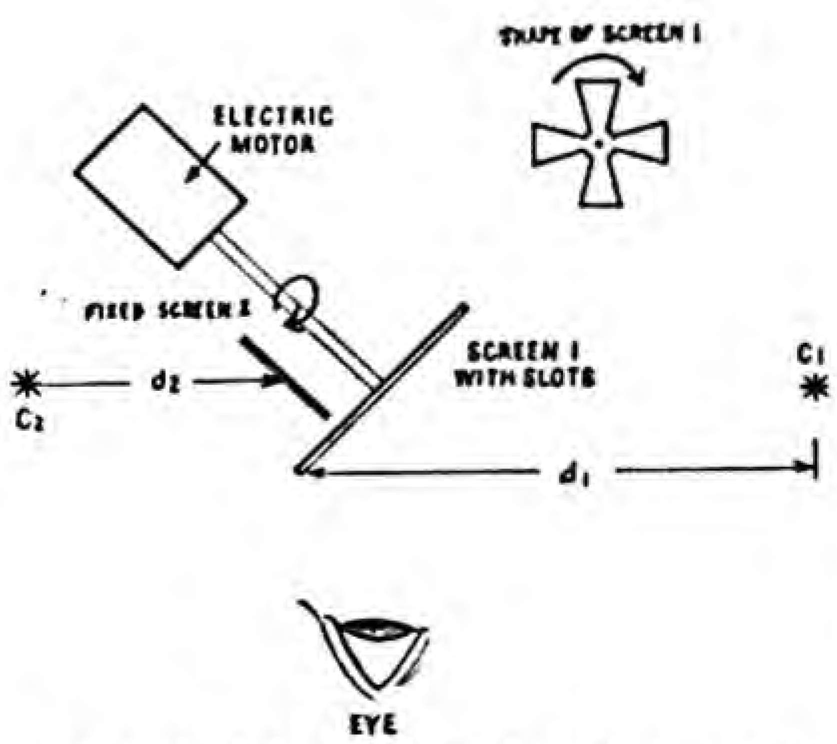
A LIGHT-METER. This is a photo-electric cell, a device which generates electricity when light falls upon it, together with a delicate electrical instrument to measure the electricity generated. It has a dial calibrated directly in foot-candles.



A typical lightmeter.



An illustration of the "Inverse Square Law".



The principle of the Flicker Photometer.

RECOMMENDED INTENSITIES OF ARTIFICIAL ILLUMINATION, IN FOOT-CANDLES

Dental surgery	35
Drawing office	35
Gymnasium	12
Hospital operating table	100 at least
Billiards table	20
Library—general	8
—on book	20
Offices	12
Classrooms	8
Art rooms	20
Laboratories	12
Woodwork rooms	12
Metalwork rooms	12
Sewing rooms	20
Engraving	50 at least
Watch-making	35

A comparison with natural daylight, on a bright summer day.

	foot-candles
In sunshine	10,000
In shade of a tree	1,000
In shade of a porch	500
Indoors, near window	200

The intensity of illumination in a room depends upon the power of the lamps employed, the type and cleanliness of the fittings, and upon the colour and nature of the walls, ceiling and furniture. There is no doubt that most private houses are seriously below standard with regard to artificial lighting. To save expense, it is a good plan to have a fairly low level of general illumination with local areas of high illumination, e.g. 8 foot-candles in a living-room, with 25 foot-candles (from a reading lamp) on a book or needlework.

PHOTOMETRY. The comparison of the candle-powers of lamps. The instrument used is a *photometer*. The lamp of known candle-power is usually an electric lamp—a "sub-standard" which has been measured against the standard itself, e.g. the platinum furnace of 60 candelas. One convenient type of photometer is the Flicker Photometer. One screen is illuminated by the lamp of known candle-power, and the other by the lamp under test. The positions of the lamps are adjusted to give equal intensities on both screens, the distances from the screens then being measured. The eye is allowed to see one screen for a fraction of a second, and then the other, in rapid alternation. There is a pronounced flickering effect until the adjustment has been made perfect.

$$\frac{C_1}{d_1^2} = \frac{C_2}{d_2^2}$$

Example: A "sub-standard" lamp of 60 c.p. is placed 3 ft. from a photometer, and is balanced by a lamp of unknown candle-power 2 ft. away.

$C_1 = 60.\ d_1 = 3.\ C_2 = ?.\ d_2 = 2.$

$$\frac{C_1}{d_1^2} = \frac{C_2}{d_2^2}$$

$$\therefore \frac{60}{3^2} = \frac{C_2}{2^2} \therefore \frac{60}{9} = \frac{C_2}{4}$$

$$\therefore C_2 = \frac{\overset{20}{\cancel{60}} \times 4}{\underset{3}{\cancel{9}}} = \frac{80}{3} = 26{\cdot}7 \text{ c.p.}$$

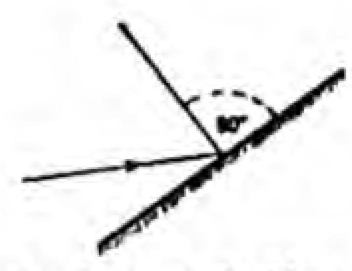
LAWS OF REFLECTION OF LIGHT.

(1) The angle of incidence is equal to the angle of reflection.

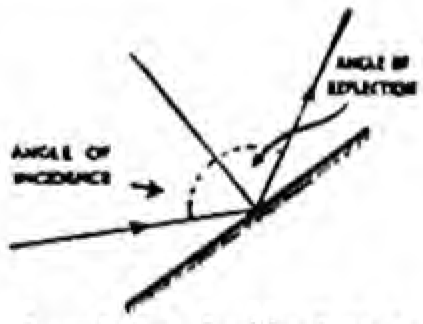
(2) The incident ray, the normal and the reflected ray are in the same plane. The meaning is that if the mirror is perpendicular to this page and the incident ray comes along the surface of the page, then the reflected ray is also along the surface of the page.

A mirror

A mirror and an incident ray

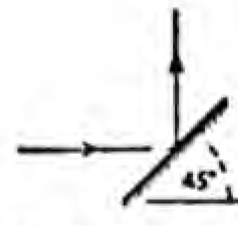


A mirror, an incident ray and a normal.

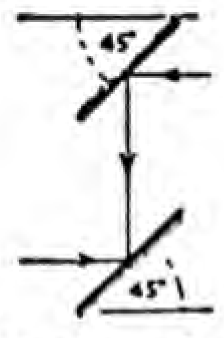


A mirror, incident ray, normal and reflected ray.

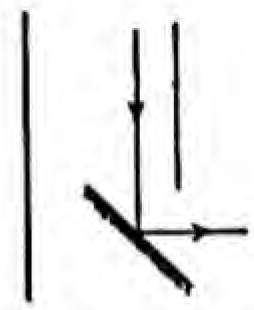
Some uses of mirrors for changing the direction of light



The view-finder of an inexpensive camera.

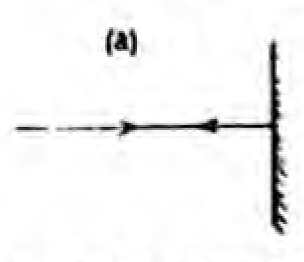


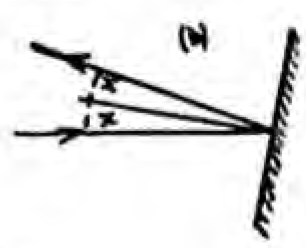
A periscope for seeing over the heads of a crowd.



To reflect light into a window close to another building.

Rotating mirrors



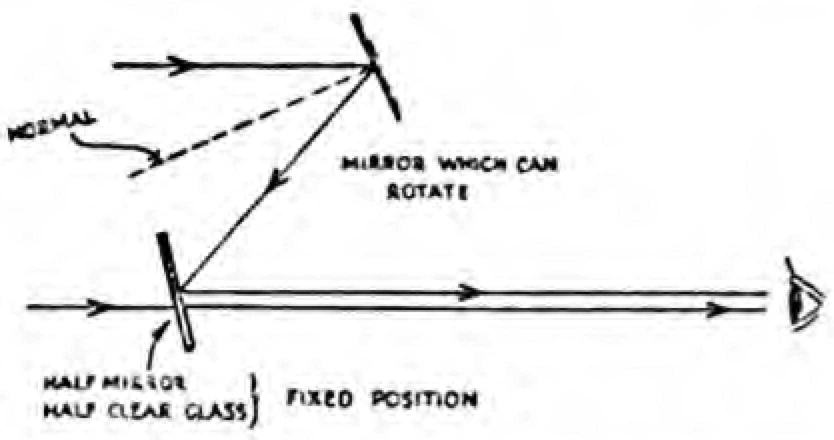


(a) angle of incidence = 0°
angle of reflection = 0°
angle between rays = 0°.

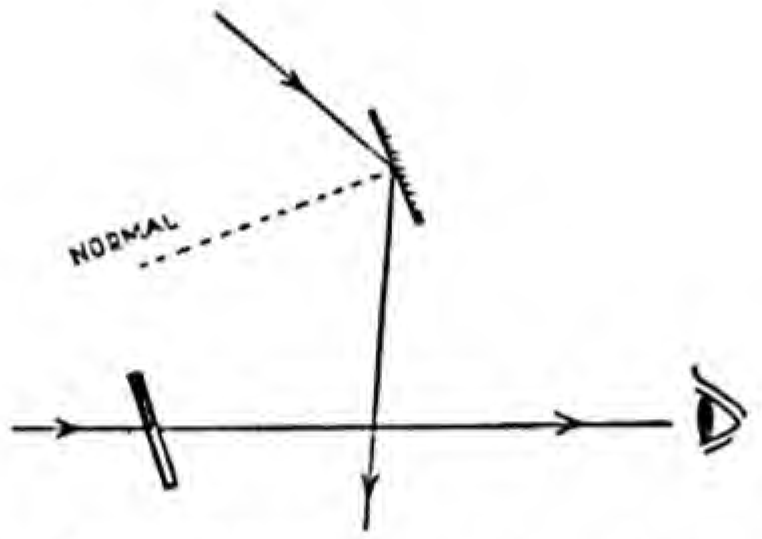
(b) mirror rotates through x°
$\therefore$ normal rotates through x°
angle of incidence = x°
angle of reflection = x°
$\therefore$ angle between rays = 2x°.

When a mirror rotates through an angle, the reflected ray turns through twice the angle.

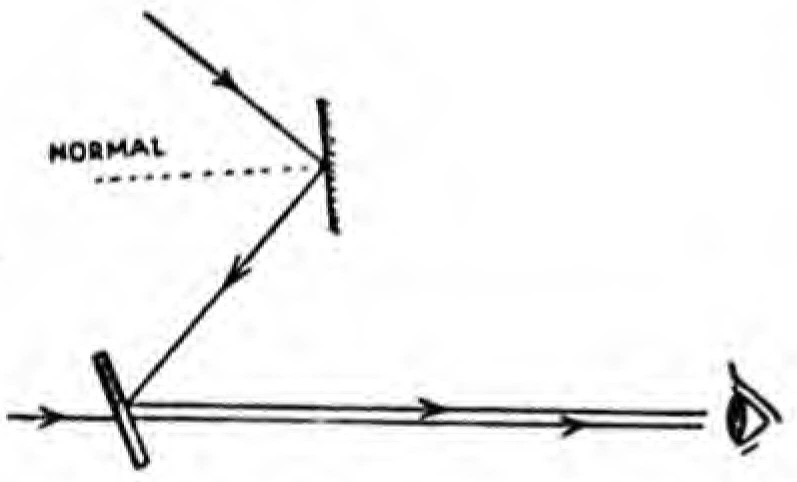
The theory of the sextant, which measures the angle, as seen by the eye, between two distant objects.



(a) The same distant object being seen directly through the clear glass, and indirectly after being reflected twice.



(b) A ray of light from an object subtending an angle of 60° with the first object does not reach the eye. To do so the reflected ray must be turned round through 60°.



(c) To do this the mirror has to be turned through *half* the angle (30°). The observer now sees the two objects, side by side, one direct and the other after two reflections.

Note: The scale on which the rotation of the mirror is read is specially calibrated, each degree being called two degrees, so that the angle between the objects is found without multiplying by two.

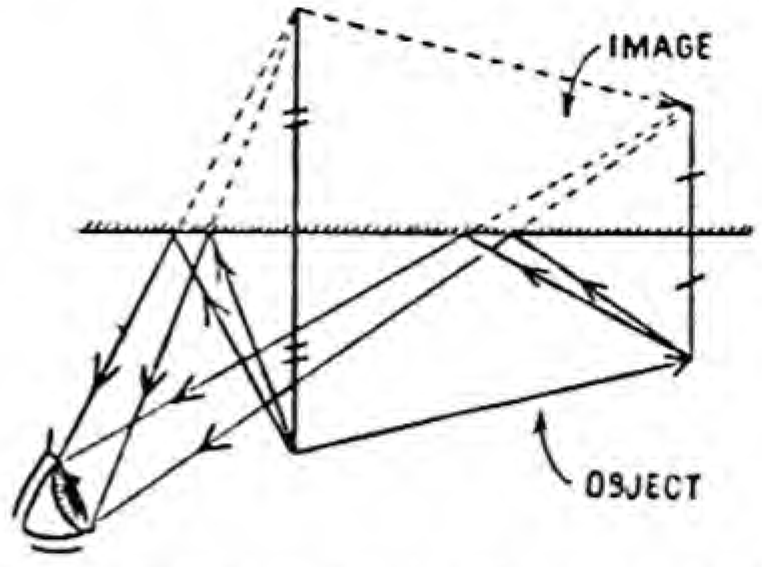
The position of the image in a mirror

It is (a) on the normal

(b) as far behind the mirror as the object is in front.

It is also laterally inverted, e.g. L looks like ⅃.

The rays by which the eye sees an image in a mirror



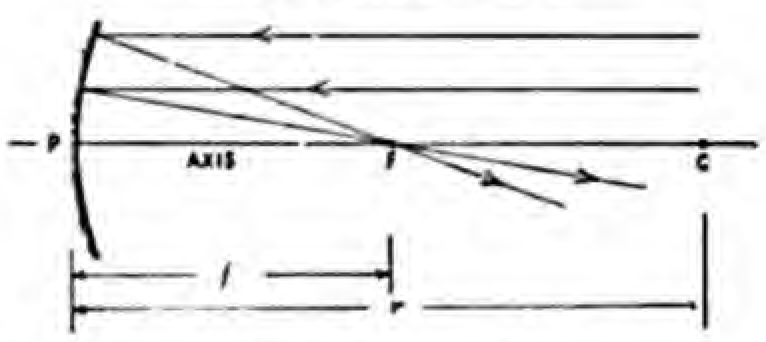
Rays of light from the object enter the eye after reflection and *appear* to have come from behind the mirror.

A spherical mirror is made from a piece of glass which would form part of a hollow glass ball. If silvered on the outside, it is a concave mirror; if on the inside, a convex mirror.

The axis (PC) of the mirror is the radius through its centre, the Pole. The Centre of Curvature is the centre of the sphere (C). The radius of curvature is the radius of the sphere (r). The Principal Focus (F) is the point through which all rays parallel to the axis pass (or appear to pass) after reflection.

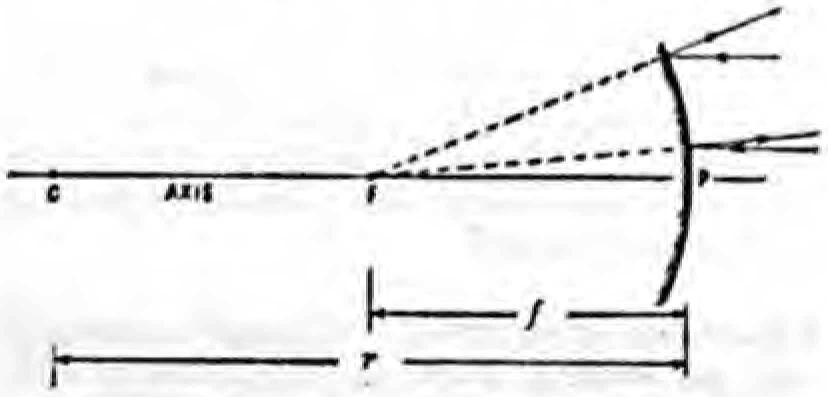
The focal length (f) is the distance between Pole and Principal Focus. Radius of curvature = 2 × focal length.

A concave mirror



Note: $r = 2f$.

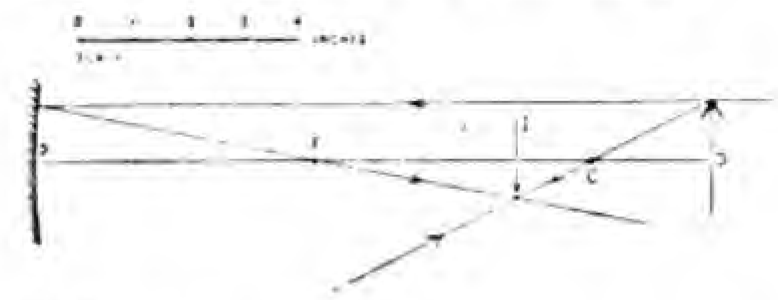
A convex mirror



In this case the principal focus is an imaginary one, as rays do not go through it, but merely appear to have come from it after reflection.

Finding, by geometrical construction, the position and size of the image of an object in front of a convex mirror

Example: Radius of curvature 10 in., object 2 in. high, 12 in. from mirror.



Steps:

(1) Draw axis and mirror, marking in P, C and F (to scale).

(2) Mark in object (O) to scale.

(3) From head of object draw a ray parallel to the axis, and its reflected ray through F.

(4) From head of object draw a ray through C. This will always hit the mirror along a normal and come back along the same path. The point where the two reflected rays cross is the image of the top of the object.

(5) Draw in the remainder of the image (I) by symmetry.

Description of image:

It is real, because reflected rays actually go there.

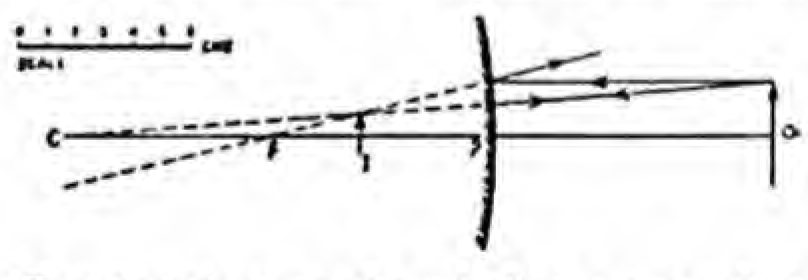
It is inverted.

It is 1·4 in. tall.

It is 8·6 in. from the mirror.

Finding, by geometrical construction, the position and size of an image in a convex mirror

Example: Radius of curvature 15 cm., object 4 cm. high and 10 cm. from mirror.



Construction exactly as before, except that rays behind mirror are imaginary and therefore dotted. The image is imaginary too—"virtual" is the special name for such an image.

Image is virtual, upright, 1·8 cm. tall, and 4·5 cm. behind mirror.

THE MIRROR FORMULAE:

(a) $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

u = distance of object
v = distance of image
f = focal length
} all measured from the mirror.

Note: Real things—POSITIVE.

Virtual things—NEGATIVE.

(b) Magnification $= \frac{I}{O} = \frac{v}{u}$

I = size of image; O = size of object. In this equation, signs are ignored.

Example 1: Concave mirror of radius of curvature 12 in. Object 4 in. high, 8 in. from mirror.

$u = +8.\ f = +6.\ v = ?.$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \qquad \frac{1}{+8} + \frac{1}{v} = \frac{1}{+6}$$

$$\therefore \frac{1}{v} = \frac{1}{+6} - \frac{1}{+8} = \frac{1}{6} - \frac{1}{8} = \frac{4-3}{24} = \frac{1}{24}$$

$v = +24.$

There is a real image 24 in. from mirror.

$$\frac{I}{O} = \frac{v}{u} \therefore \frac{I}{4} = \frac{24}{8} = \frac{3}{1}$$

$\therefore I = 3 \times 4 = 12$ in. tall.

Example 2: Concave mirror, focal length = 9 in. Object 6 in. from mirror. Find magnification.

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{+6} + \frac{1}{v} = \frac{1}{+9}$$

$$\frac{1}{v} = \frac{1}{+9} - \frac{1}{+6} = \frac{1}{9} - \frac{1}{6} = \frac{2-3}{18} = -\frac{1}{18}$$

$$\therefore v = -18$$

Image is virtual, and 18 inches behind mirror.

Magnification $= \frac{v}{u} = \frac{18}{6} = 3.$

Note: All real images are inverted, and all virtual images are upright.

Example 3: Convex mirror, focal length 10 cm., object 20 cm. from mirror. Find magnification.

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{+20} + \frac{1}{v} = \frac{1}{-10}$$

$$\frac{1}{v} = \frac{1}{-10} - \frac{1}{+20} = \frac{-1}{10} - \frac{1}{20} = \frac{-2-1}{20}$$

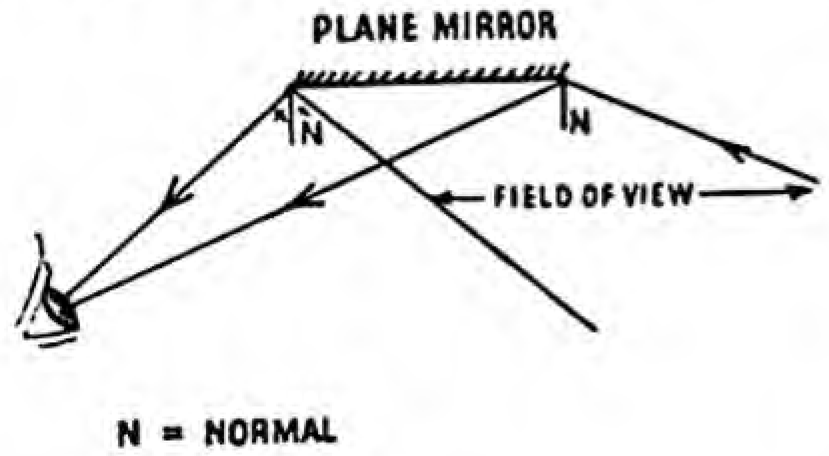
$$= \frac{-3}{20}$$

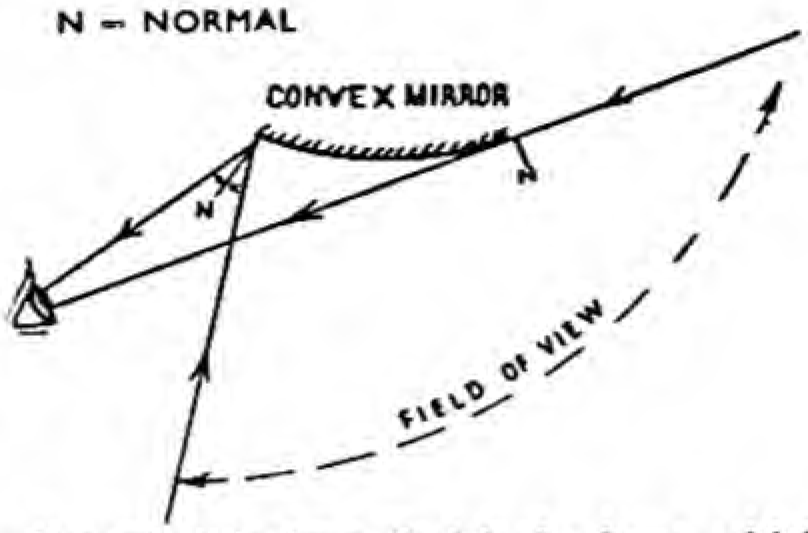
$$\therefore v = \frac{-20}{3} = -6\tfrac{2}{3}.$$

Magnification $= \frac{v}{u} = \frac{6\frac{2}{3}}{20} = \frac{20}{3} \div 20 = \frac{1}{3}.$

The image is virtual (because of negative sign), upright (because it is virtual) and one-third the size of the object.

The convex driving mirror gives a greater field of view for the motorist.



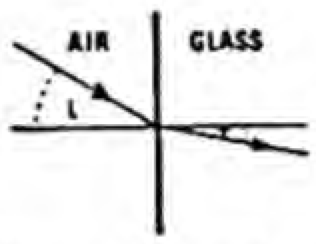


Best of all is the cylindrical mirror, which gives a very wide view in the horizontal plane, but a normal field of view in the vertical plane—it shows both sides of the road, but not the road surface nor the sky above.

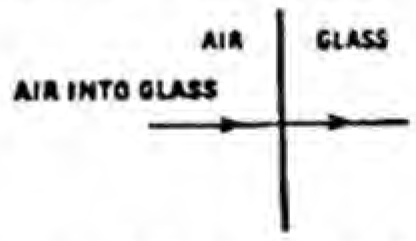
REFRACTION

Refraction is the bending of light as it passes from one transparent substance into another, e.g. from air into glass, or from water into air.

Example 1: Air into Glass.

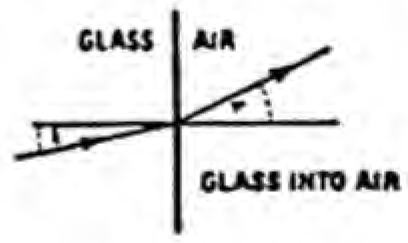


Angle of incidence > angle of refraction: ray is bent toward the normal.



Ray along normal (i.e. angle of incidence = 0°) is not bent.

Example 2: Glass into air.



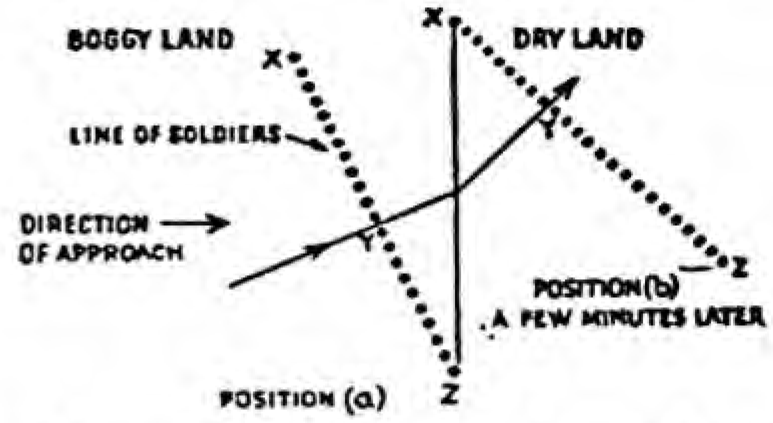
$$\hat{r} > \hat{i}$$

Ray is bent away from the normal.

General Rule: When a ray of light passes from a dense substance (e.g. glass) into a less dense (e.g. air) it is refracted away from the normal, unless it approaches the surface of separation along the normal, when its path is unchanged.

Explanation of refraction: Change in speed of light on passing from one transparent substance to another of different density.

Compare with a long line of soldiers, on boggy land, and just reaching firm land.



Private Z has been on firm land the whole time, so has gone a long way. Private X has been in the swamp and has moved forward slowly. Y has had some good and some bad going. As a result the whole line has wheeled round—has been "refracted".

Refractive index of light passing from air into glass, written $a\mu g$ (μ is pronounced "mu")

$$= \frac{\text{speed of light in air}}{\text{speed of light in glass}} = \frac{3}{2}.$$

$a\mu g$ is also the sine of the angle of incidence divided by the sine of the angle of refraction (see p. 47).

$$a\mu g = \frac{\sin i}{\sin. r}$$

Refractive indices	
Air to glass	$1{\cdot}50 = \frac{3}{2}$
Air to water	$1{\cdot}33 = \frac{4}{3}$
Air to diamond	2·40
Air to ice	1·31
Air to paraffin oil	1·44

Calculations on refractive index

Example 1: A ray of light passes from air to glass with an angle of incidence of 30°. Find angle of refraction.

$$a\mu g = \frac{\sin i}{\sin r} = 1{\cdot}5.$$

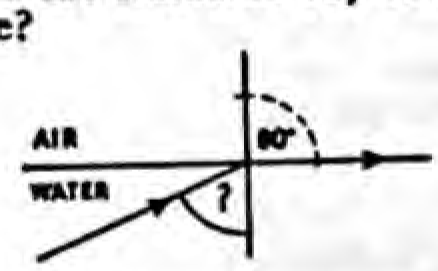
From mathematical tables, "Natural sine" of 30° = ·5.

$$\therefore a\mu g = \frac{\cdot 5}{\sin r} = 1{\cdot}5 \quad \therefore \sin r = \frac{\cdot 5}{1{\cdot}5} = \frac{1}{3}$$

$= \cdot 333$

From the tables again, the angle with a "Natural sine" of ·333 is 19°, so angle of refraction is 19°.

Example 2: What must be the angle of incidence of a ray of light passing from water into air for the refracted ray to skim along the surface?



$$a\mu w = \frac{4}{3} \qquad w\mu a = \frac{3}{4}$$

$$\frac{\sin i}{\sin 90^\circ} = \frac{\sin i}{1} = \frac{3}{4} \quad \therefore \sin i = \frac{3}{4} = \cdot 75$$

$$\therefore \hat{i} = 49^\circ.$$

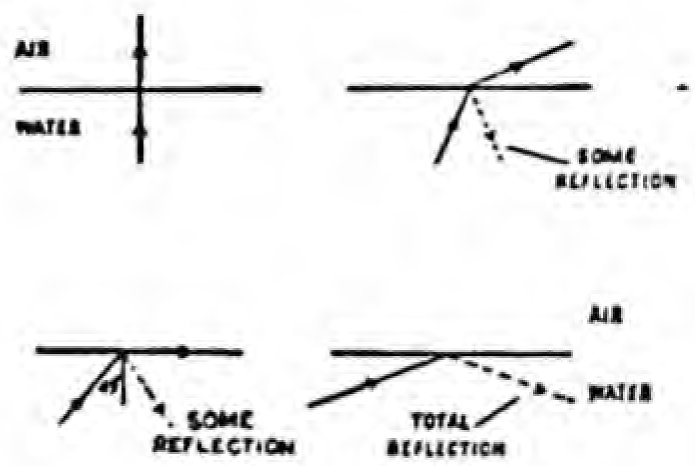
CRITICAL ANGLE. The angle of incidence for which the refracted ray passes along the surface of separation is the *critical angle.*

Critical angle for water $= 49°$

Critical angle for glass $= 42°$

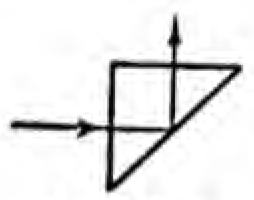
Critical angle for diamond $= 25°$

Total internal reflection. Reflection always takes place from a surface when refraction takes place through it. When the angle of incidence is greater than the critical angle, refraction cannot take place and *all* the light is reflected back into the substance.

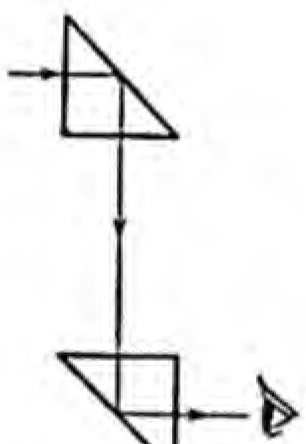


Useful application of total internal reflection

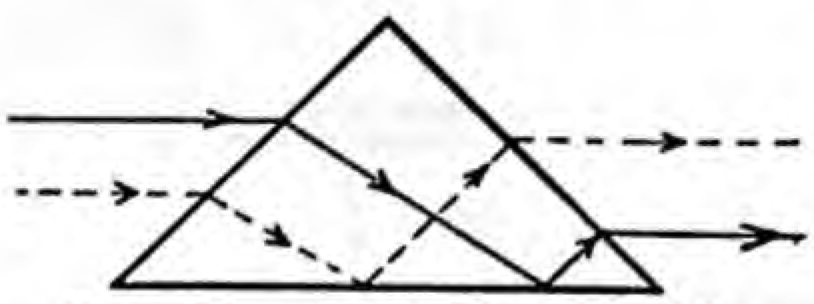
Right-angled glass prism. $\hat{i} = 45°$ in each case > critical angle, 42°.



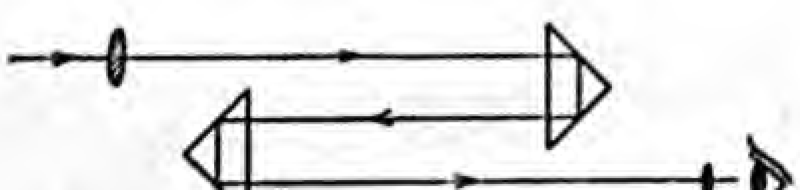
Camera viewfinder



Prismatic periscope



To make an inverted image upright.



To enable a long telescope to be "folded" to give short prismatic binoculars.

A diamond glitters naturally because of the very small critical angle. Many of the rays of light entering it are reflected back to the eye. The special cutting increases this effect.

A cut diamond.

The geometrical method for constructing refracted rays

Step 1: Draw surface and incident ray.

Step 2: Draw the two circles in proper proportion (radii 3 and 2 for glass; 4 and 3 for water).

Step 3: Draw perpendicular where circle representing *denominator* of refractive index $\left(\text{e.g. } 2 \text{ for } {}_a\mu_g = \frac{3}{2}\right)$ cuts incident ray.

Step 4: Draw refracted ray from point where perpendicular ray cuts the circle representing the numerator $\left(3 \text{ for } {}_a\mu_g = \frac{3}{2}\right)$.

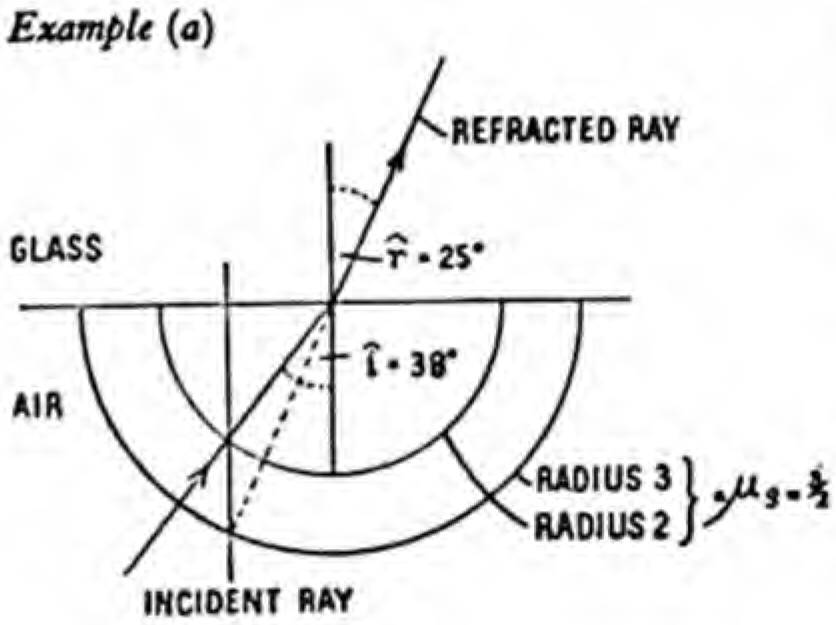
Example (a) is one of this type.

Example (b) deals with ${}_w\mu_a = \frac{3}{4}$.

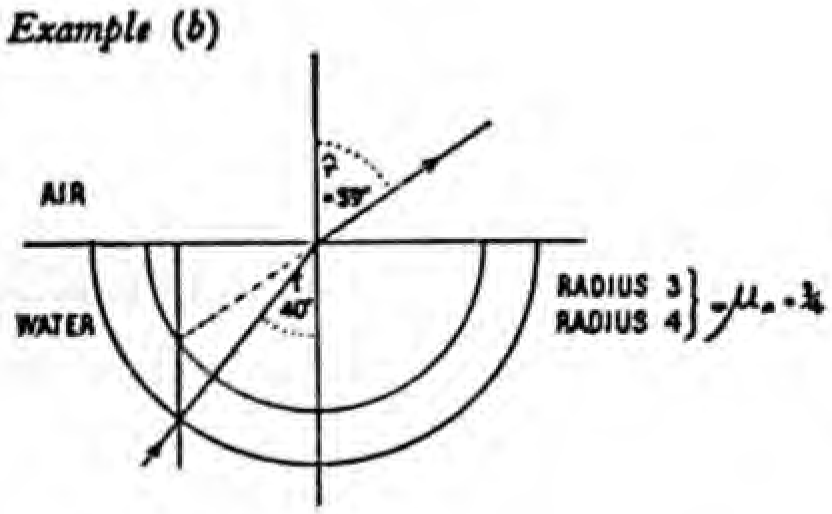
Example (c) finds the critical angle for ${}_w\mu_a = \frac{3}{4}$.

Example (d) will not work ∴ no refraction ∴ total internal reflection.

Example (a)

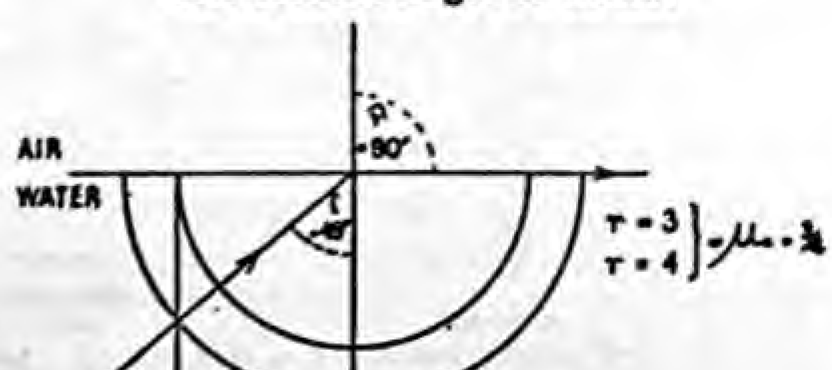


Example (b)



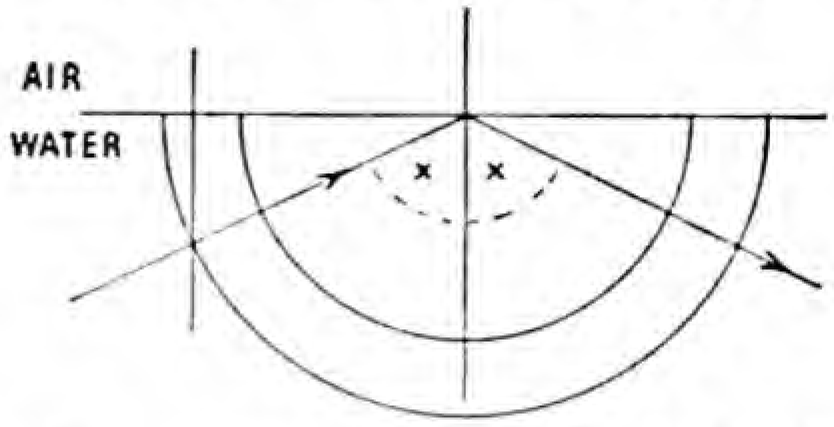
Example (c)

The critical angle of water.



Example (d)

Total internal reflection with water.

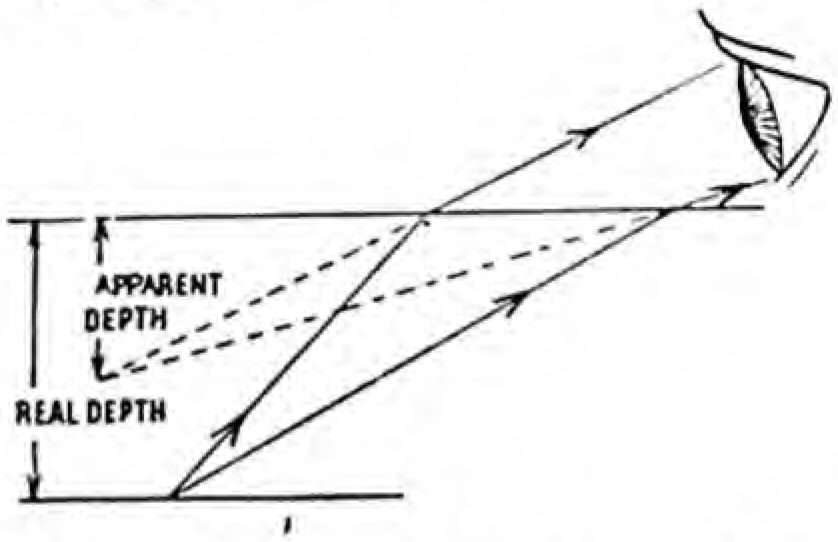


Remember, angle of incidence = angle of reflection.

Apparent depth

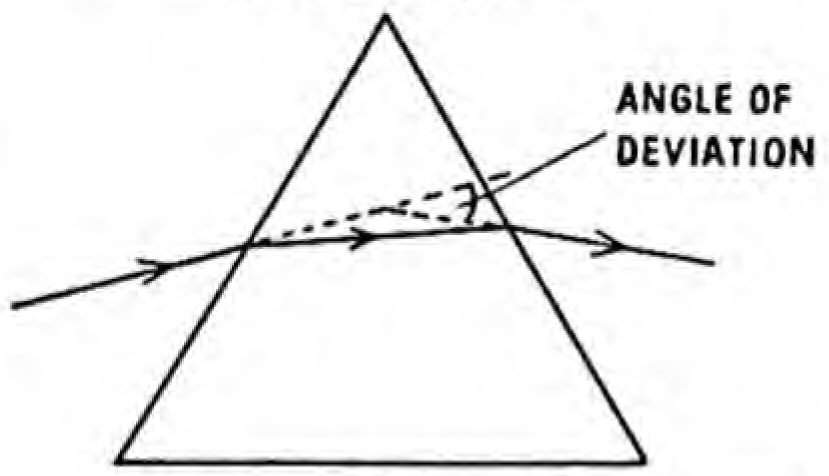
Due to refraction, a transparent material looks less deep than it really is.

Explanation:

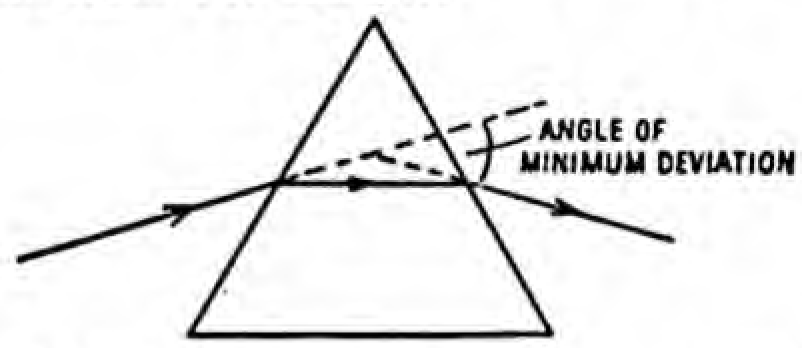


If one looks vertically downward, the apparent depth of water $= \frac{3}{4}$ the real depth. (${}_w\mu_a = \frac{3}{4}$); and of glass, $\frac{2}{3}$ the real depth (${}_g\mu_a = \frac{2}{3}$).

The deviation produced by refraction through a prism



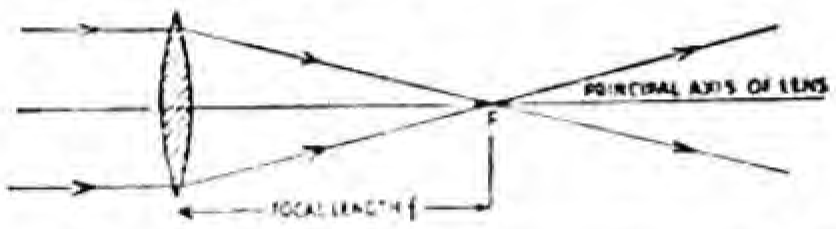
When the prism is turned, the refracted ray is found to reach a minimum position, and then retrace its path (although the prism is still rotated in its original direction). In the position of minimum deviation the path of the ray of light in the prism is symmetrical. For example:



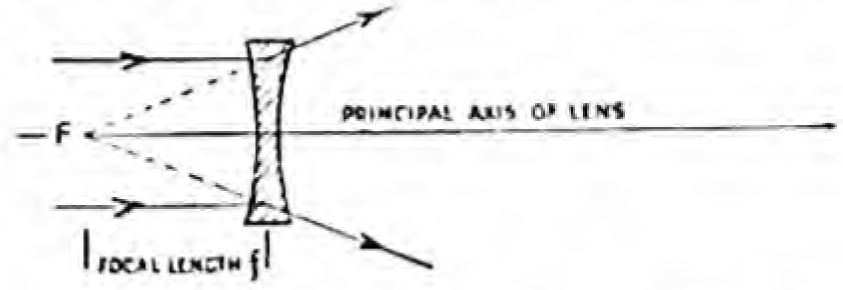
Note: Ray of light in prism is parallel to the base.

This is the best position for a prism when it is needed to split up white light into its component colours.

LENSES. A *convex* lens is a converging lens —it has a real principal focus.



A *concave* lens is a diverging lens—it has a virtual (imaginary) principal focus.



The principal focus of a lens (F) is the point to which light parallel to the principal axis is converged, or from which it appears to diverge, after refraction through the lens.

The focal length is the distance between the centre of the lens and the principal focus.

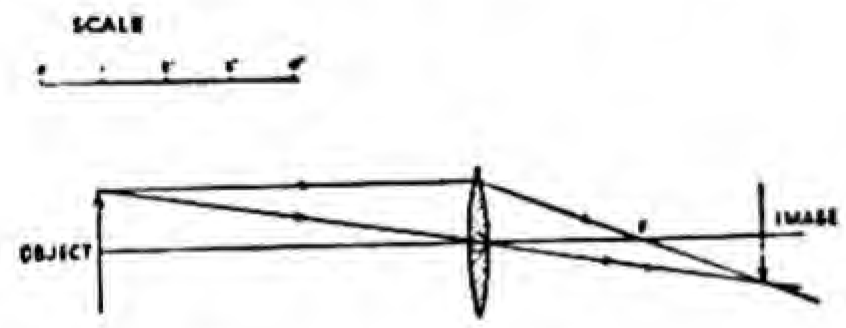
Geometrical Construction for Lenses :

(1) A ray from the top of the object, parallel to the principal axis, is refracted through the principal focus.

(2) A ray from the top of the object passes through the centre of the lens unchanged in direction.

(3) The point of intersection of the two refracted rays gives the position of the top of the image. The bottom is drawn in symmetrically.

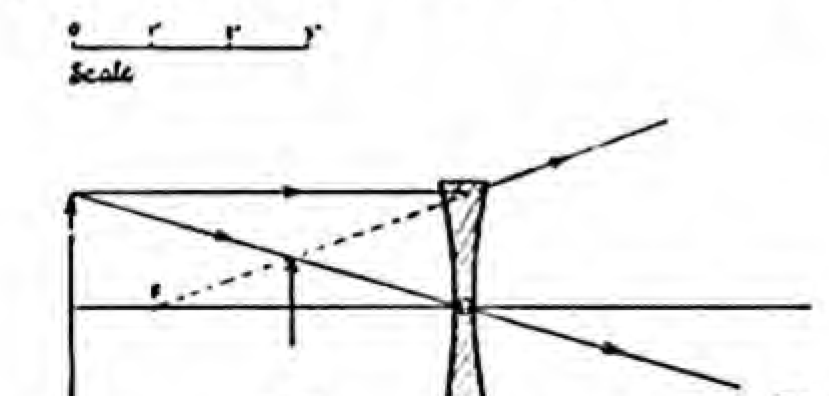
Example 1 : An object of length 2 in. is placed 6 in. in front of a convex lens of focal length 2·5 in. Find position and size of image.



O = centre of the lens.

The image is inverted. It is 4·3 in. from the centre of the lens and 1·4 in. long.

Example 2 : An object 3 in. tall is 5 in. from a concave lens of focal length 4 in. Give the position and size of the image.

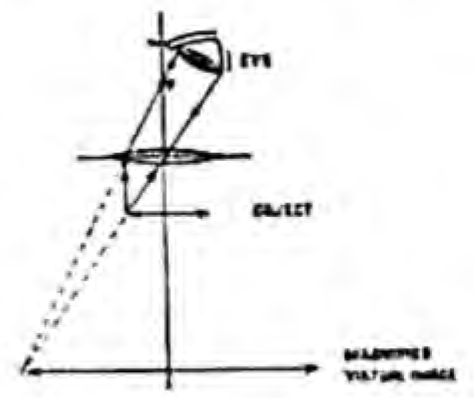


The image is upright and virtual, being on the same side of the lens as the object and seen by looking through it. It is 2·2 in. from the lens and 1·3 in. tall.

Geometrical constructions used to explain the action of some common uses of lenses.

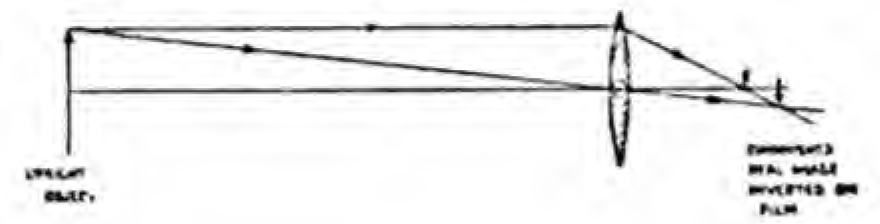
1. The simple magnifying glass

Convex lens with object nearer to lens than F.

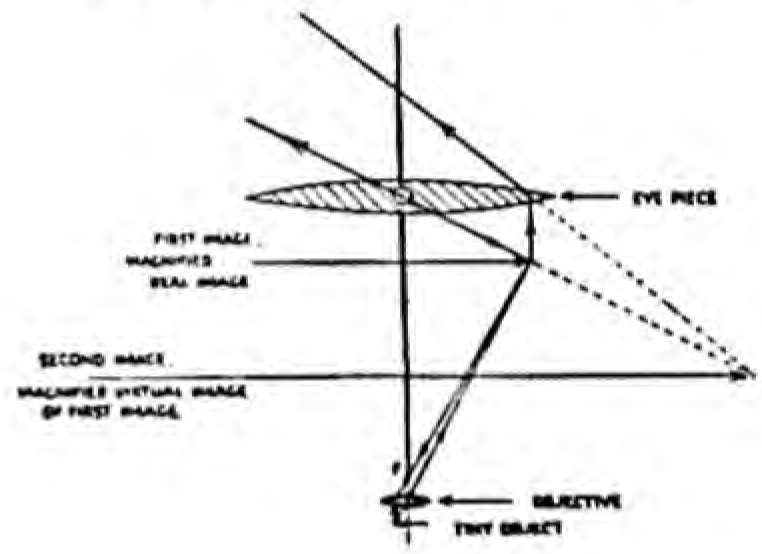


2. The camera

Convex lens with object far away.

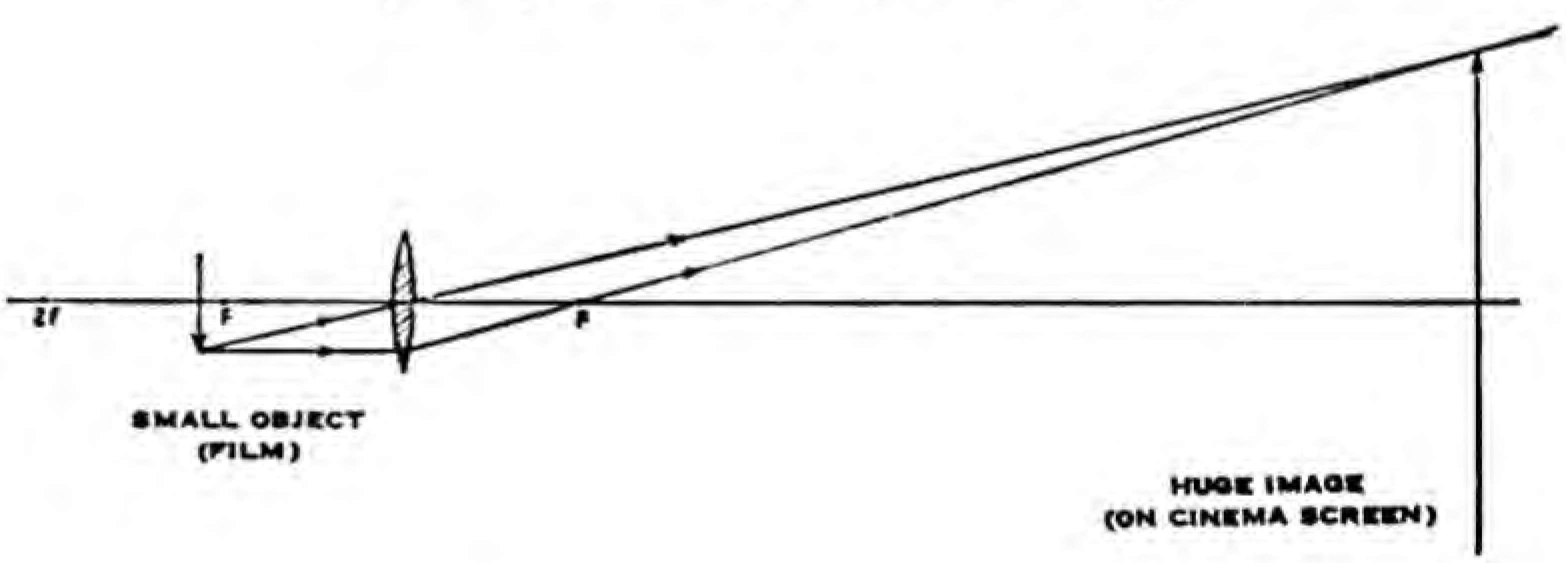


3. The compound microscope



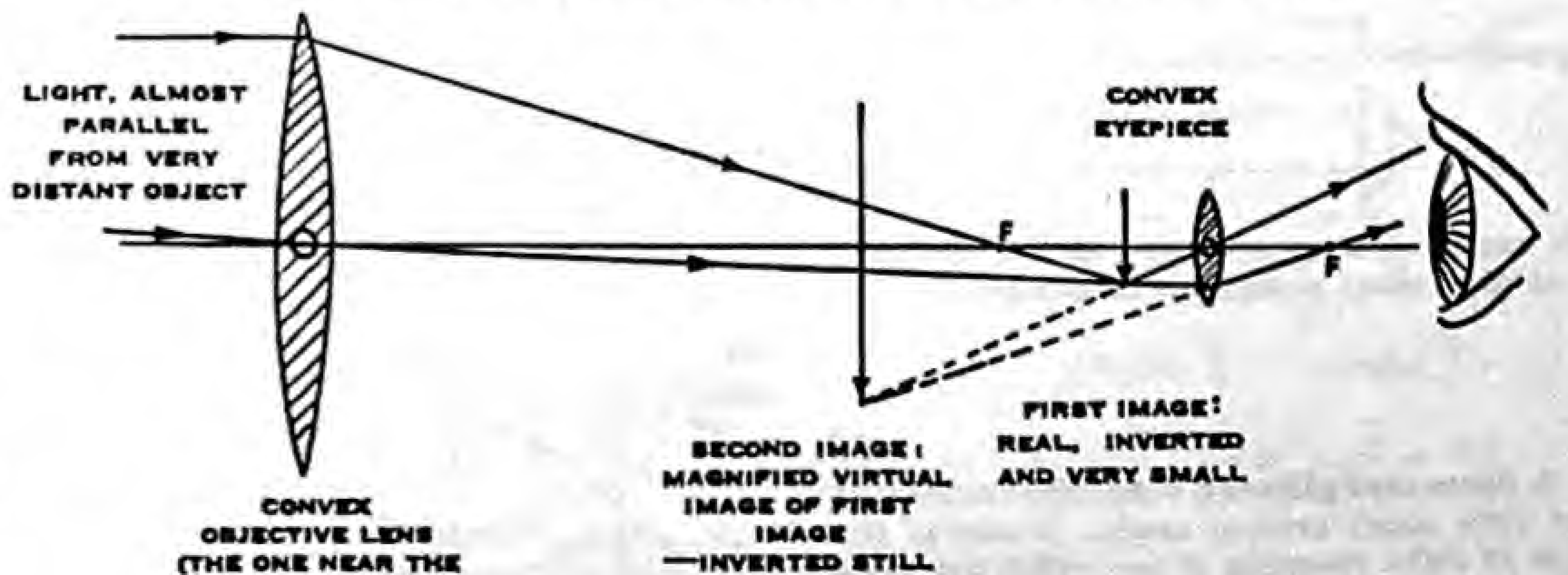
4. The projecting lens of a lantern (or cinematograph)

Convex lens, with slide (or film) upside down, and between F and 2F. (2F = point twice as far from lens as F.)

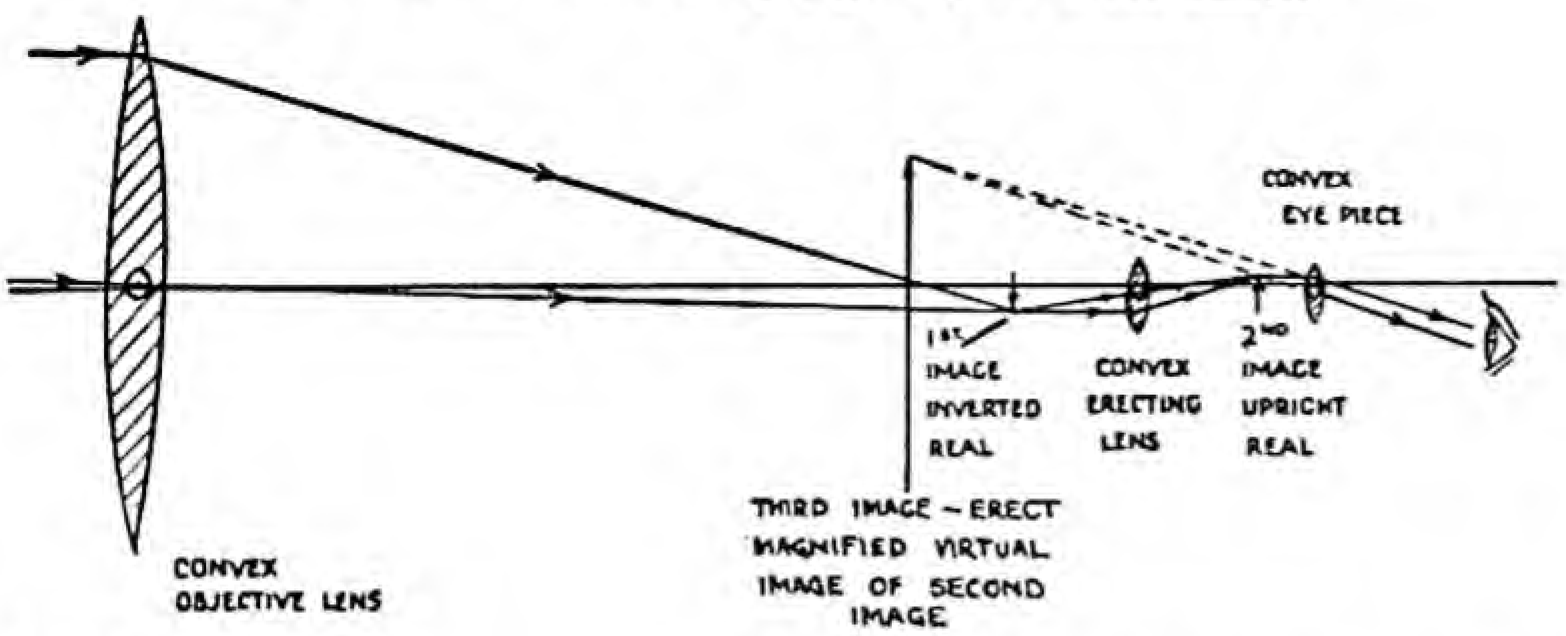


5. An astronomical telescope

An inverted image of the moon or of a star is not a drawback.



6. A terrestrial telescope, giving an erect image



Types of lenses met in practice.

The Lens Formulae.

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

where u = distance of object from lens,

v = distance of image from lens, and

f = focal length of lens.

The distance associated with a virtual image or a virtual focus is negative—positive for real.

$$M = \frac{I}{O} = \frac{v}{u}$$

where I = length of image, M = magnification and O = length of object. (Signs are ignored in this equation.)

Example 1: A cinema "frame", 35 mm. in length, is placed 3 cm. from a convex lens of focal length 2·9 cm. Where will the image be formed and what will be the length of the projected image?

$u = +3$ cm. $v = ?$ cm. $f = +2{\cdot}9$ cm.

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \therefore \frac{1}{+3} + \frac{1}{v} = \frac{1}{+2{\cdot}9}$$

$$\therefore \frac{1}{v} = \frac{1}{2{\cdot}9} - \frac{1}{3} = \frac{3 - 2{\cdot}9}{3 \times 2{\cdot}9} = \frac{{\cdot}1}{8{\cdot}7} = \frac{1}{87}$$

$$\therefore v = 87 \text{ cm.}$$

$$\frac{I}{O} = \frac{v}{u} \therefore \frac{I}{35} = \frac{87}{3} = 29$$

$$\therefore I = 29 \times 35 \text{ mm.} = 1{,}015 \text{ mm.} = 101{\cdot}5 \text{ cm.}$$

Example 2: Describe the image of an object which is 8 in. from a concave lens of focal length 4 in.

$u = +8$ $v = ?$ $f = -4$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \therefore \frac{1}{+8} + \frac{1}{v} = \frac{1}{-4}$$

$$\therefore \frac{1}{v} = -\frac{1}{4} - \frac{1}{8} = \frac{-2-1}{8} = \frac{-3}{8}$$

$$\therefore v = -\frac{8}{3} = -2{\cdot}67 \text{ in.}$$

The image is virtual (negative sign). It is upright (since all virtual images are erect). It is 2·67 in. from the lens. The magnification $= \frac{v}{u} = \frac{2{\cdot}67}{8} = \frac{1}{3}$.

The power of a lens. A lens of short focal length is a powerful lens.

The Dioptre. This is the unit of power employed by opticians. It is the focal length of a lens (in metres) divided into one.

Examples: Convex lens, focal length 1 m.

(100 cm.): Power $= \frac{1}{+1} = +1$ dioptre.

Convex lens, focal length $\frac{1}{2}$ m. (50 cm.):

Power $= \frac{1}{+\frac{1}{2}} = +2$ dioptres.

Concave lens, focal length 2 m.:

Power $= \frac{1}{-2} = -\frac{1}{2}$ dioptre.

Combined lenses. A convex lens of power + 4 dioptres is combined with a concave lens of − 3 dioptres. The power of both lenses together = the sum of their individual powers = + 4 dioptres + (− 3) dioptres = (4 − 3) = + 1 dioptre.

The combination has the power of + 1 dioptre, i.e. it behaves like a convex lens of focal length 1 m.

The aperture of a photographic lens. The "exposure" in photography depends upon the strength of the light and on the "aperture" of the lens. This is stated as an "f number", e.g. f4·5. This really should read $\frac{f}{4{\cdot}5}$, for, in this case, the diameter of the hole through which light enters the camera, through the lens is the focal length ÷ 4·5. If a lens has a focal length of 9 in., and the diameter is 1 in., the aperture $= \frac{f}{9}$, i.e. f/9 or f9.

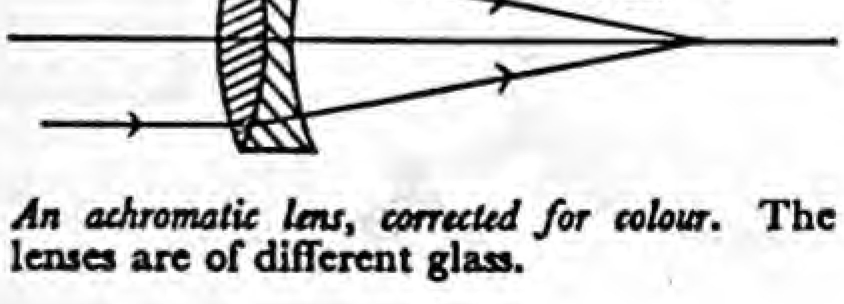
Colour. Light is wave-motion in the ether, like radio and radiated heat. Different colours have different wave-lengths.

APPROXIMATE WAVE-LENGTHS	
Violet	425×10^{-9} metres, i.e. ·000000425 metres
Blue	475×10^{-9} metres
Green	525×10^{-9} metres
Yellow	575×10^{-9} metres
Orange	615×10^{-9} metres
Red	650×10^{-9} metres

Complementary colours are two colours which produce white when *added* together (e.g. by shining lamps of the two colours on to the same screen, not by mixing paints).

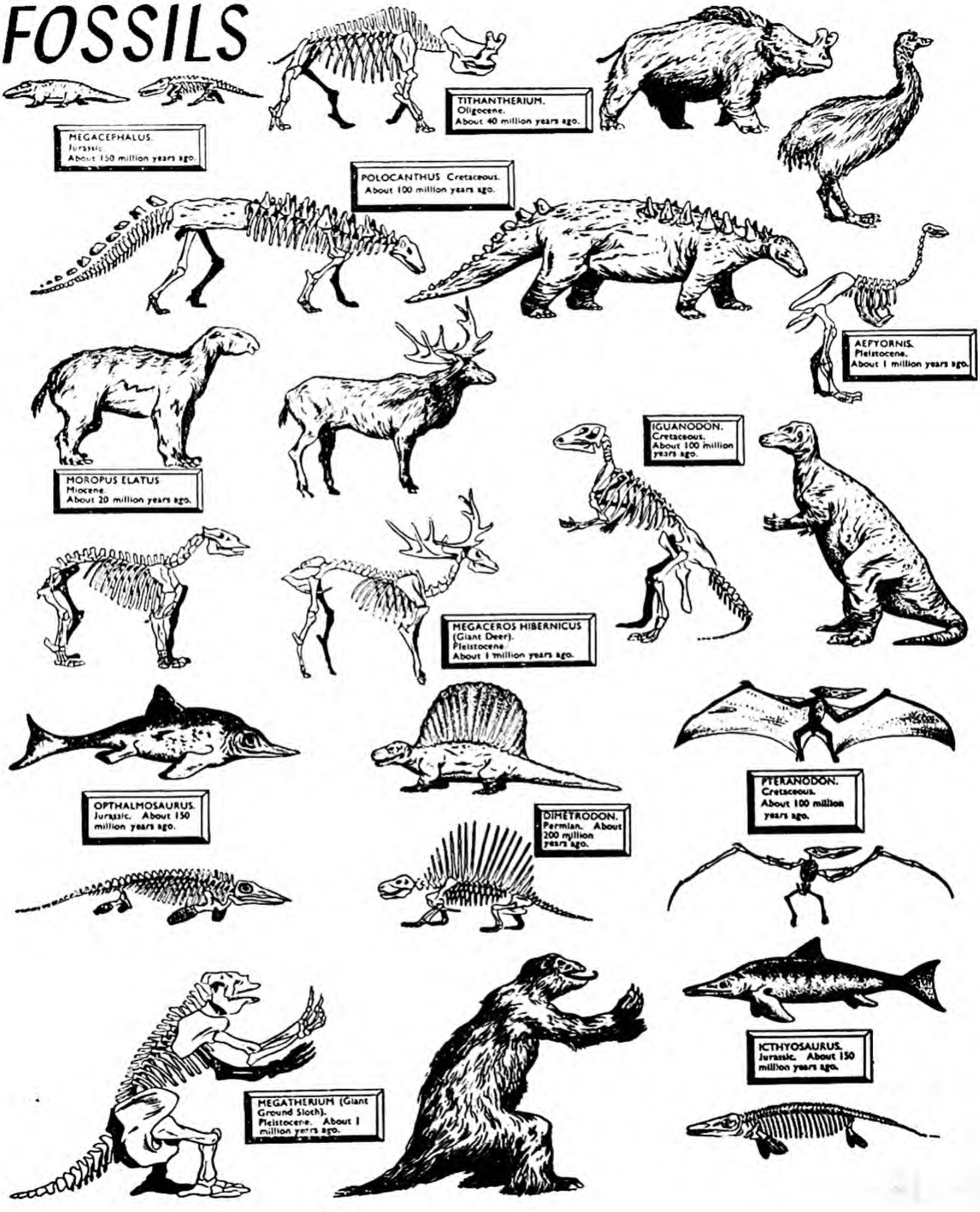
Examples: Red and peacock blue
Yellow and blue
Green and magenta.

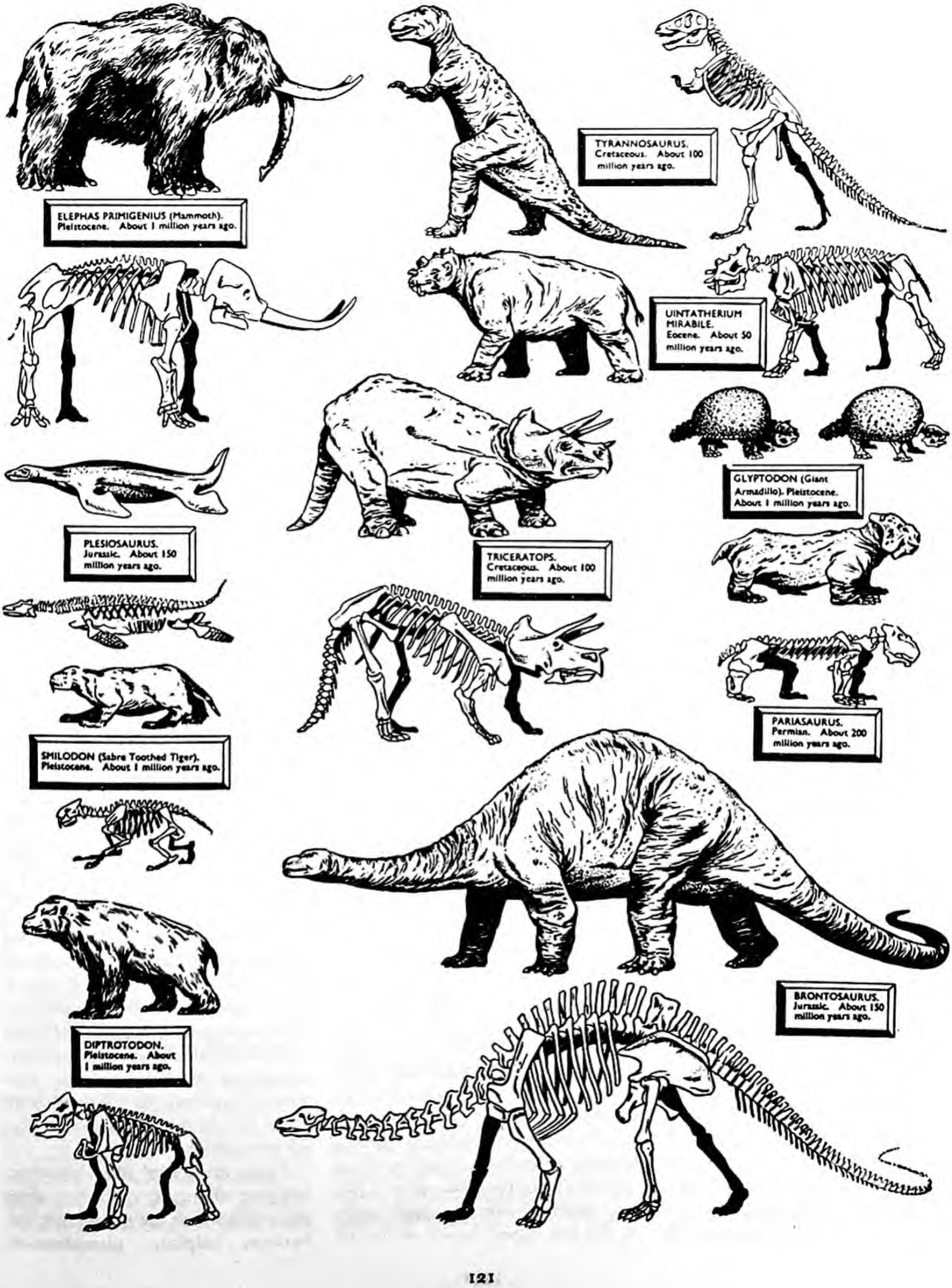
Compound lenses. A simple lens refracts light of different colour slightly differently, so if the image of a blue object is sharply in focus that of a red one in the same position is blurred because it is "out of focus".



An achromatic lens, corrected for colour. The lenses are of different glass.

FOSSILS


MEGACEPHALUS. Jurassic. About 150 million years ago.
TITHANTHERIUM. Oligocene. About 40 million years ago.
POLOCANTHUS Cretaceous. About 100 million years ago.
AEPYORNIS. Pleistocene. About 1 million years ago.
MOROPUS ELATUS Miocene. About 20 million years ago.
IGUANODON. Cretaceous. About 100 million years ago.
MEGACEROS HIBERNICUS (Giant Deer). Pleistocene. About 1 million years ago.
OPTHALMOSAURUS. Jurassic. About 150 million years ago.
DIMETRODON. Permian. About 200 million years ago.
PTERANODON. Cretaceous. About 100 million years ago.
MEGATHERIUM (Giant Ground Sloth). Pleistocene. About 1 million years ago.
ICTHYOSAURUS. Jurassic. About 150 million years ago.


ELEPHAS PRIMIGENIUS (Mammoth). Pleistocene. About 1 million years ago.
TYRANNOSAURUS. Cretaceous. About 100 million years ago.
UINTATHERIUM MIRABILE. Eocene. About 50 million years ago.
GLYPTODON (Giant Armadillo). Pleistocene. About 1 million years ago.
PLESIOSAURUS. Jurassic. About 150 million years ago.
TRICERATOPS. Cretaceous. About 100 million years ago.
PARIASAURUS. Permian. About 200 million years ago.
SMILODON (Sabre Toothed Tiger). Pleistocene. About 1 million years ago.
BRONTOSAURUS. Jurassic. About 150 million years ago.
DIPTROTODON. Pleistocene. About 1 million years ago.

THE CHEMIST AT WORK

The work that chemists have done since this science began has been to find out what difference there is between two substances that seem the same and yet behave differently when in contact with another substance. A liquid that looks like water is not necessarily safe to drink—it can be a deadly poison.

To start with, the chemist makes certain that the substance he is investigating is in fact only one substance and not a *mixture* of several. The ways mixtures are separated into pure substances are described on the opposite page.

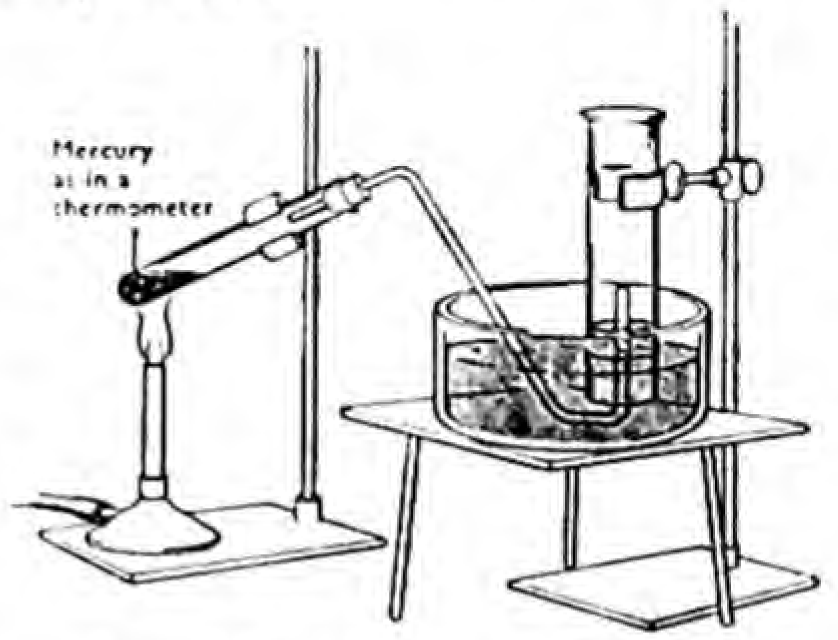
A pure substance is identified and classified by the way it reacts chemically with other pure substances. These combinations follow set patterns, so there are laws of Chemistry, just as there are laws of Physics. Not only are all natural substances classified by these patterns of combination, but because there are so many possible combinations (not found in nature) that follow the simple rules chemists are continually making new substances. Some of these are useful on their own, others simplify industrial processes by providing a link in a whole chain of reactions.

Analysis is the use of the same laws in reverse. A substance of which nothing is known is tried by a series of tests. These tests can be plotted like a shunting yard, each set of points (a test) deciding which track the truck runs down next, dividing and dividing until there is only one substance known to have all those particular attributes.

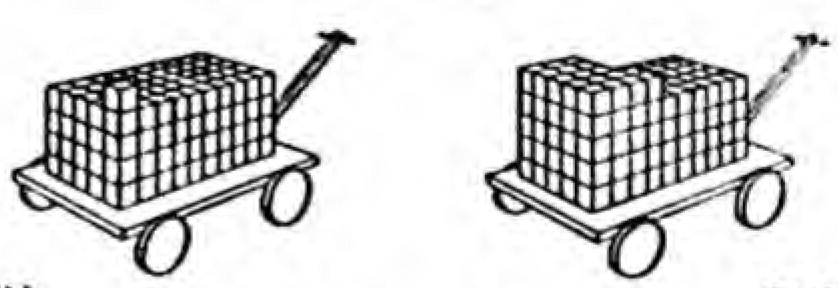
The effect of destructive heating on substances that seem pure can be quite surprising. Some materials lose weight on heating, but often what is left after heating weighs more than the original substance!

During hundreds of years before real chemistry began, the alchemists had heated everything they could think of. Eventually some of them, more curious and careful than the rest, thought of weighing the "ashes" and of catching the "steam" that some things give off when heated.

These are the sort of recipes they wrote:



If heated long enough, all the mercury will change into black flakes which later become red. As it does so, the water-level rises in the jar, showing that a part of the air in it has been used up.

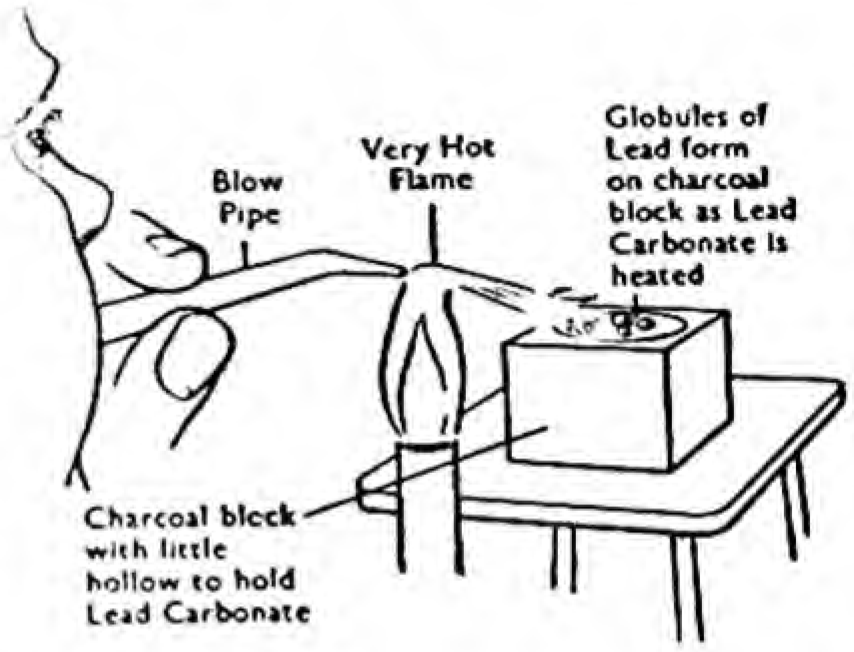


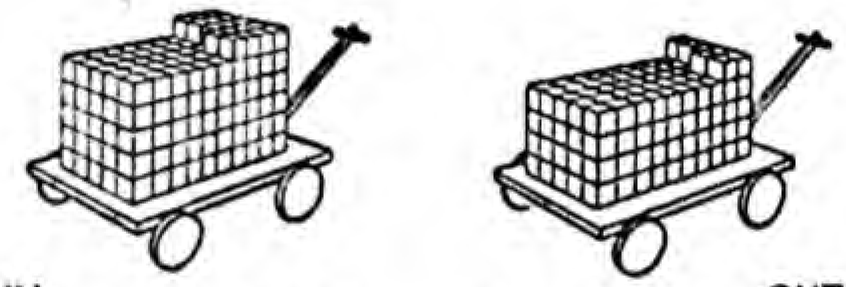
IN
201 parts by weight of Mercury

OUT
217 parts by weight of Mercuric Oxide

What is left weighs more than what was put in. If, instead of disconnecting the apparatus to weigh it, the red substance had been heated still more, the water-level in the jar would have gone down again by the amount it has previously risen—showing that whatever was taken from the air is being given back—and in place of Mercuric Oxide—plain Mercury would have appeared again in the test tube.

Another similar discovery, was that one of the ores of lead that is found in nature, and which we now call Lead Carbonate, if heated very strongly in the presence of charcoal will yield little globules of the metal Lead.





IN
267 parts by weight of Lead Carbonate

OUT
207 parts by weight of Lead

The same substance can be obtained in various ways, very often from a whole number of different substances. For instance:

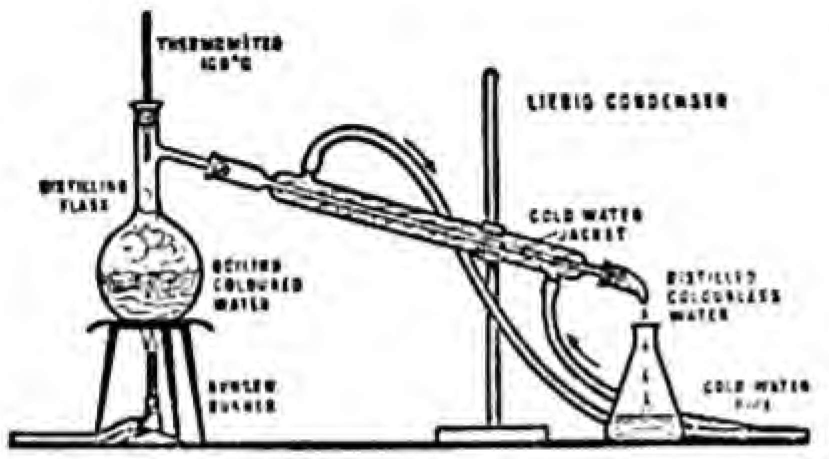
parts by weight of		parts by weight of Iron
72	Ferrous Oxide	56
160	Haematite contains	112
160	Jeweller's rouge contains	112
232	Magnetite contains	168
120	Yellow Iron Pyrites contains	56
104	Green Vitriol contains	56

It seems likely that the metal Iron is one of the basic ingredients of a good many substances, in fact, as the early chemists discovered, there are quite a number of these main ingredients, each of which is contained in several other substances and can be released from them by chemical reactions. Not all are metals.

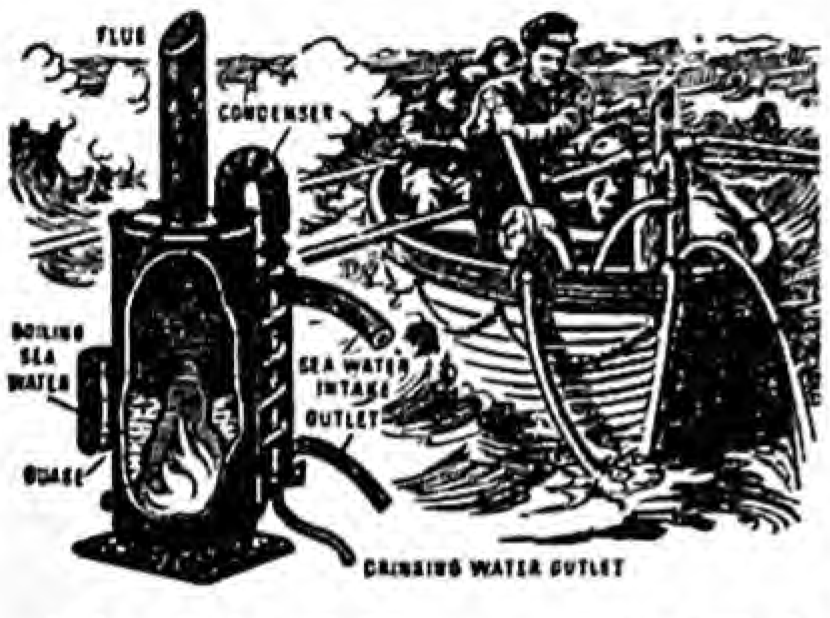
Some are gases, like hydrogen, oxygen, nitrogen, chlorine; some are solids which are not metals, like carbon, sulphur, phosphorous;

Distillation

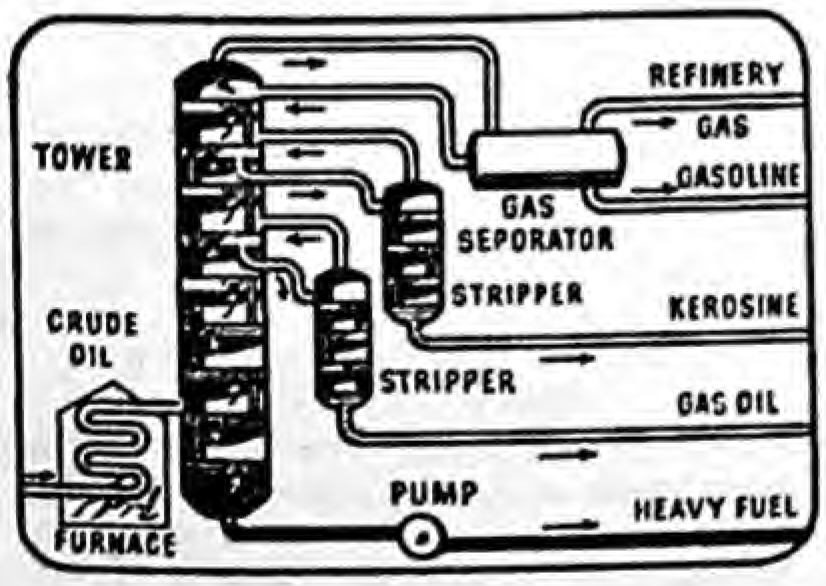
1. One of the earliest and most simple methods of purifying a liquid is by distillation, the process of converting the liquid into vapour by heating, the impurities being left behind. The vapour is then led elsewhere and cooled to condense it back to a liquid. Pure water can be obtained by this method.



2. The Liebig condenser, a usual type of apparatus for distillation used in the laboratory. To purify water containing an impurity (such as a colouring substance), the liquid is heated in the distilling flask to its boiling point when it vaporises. The vapour is led through a long glass tube which is enclosed by another tube in which cold water is circulating. In passing through the inner tube, the vapour is condensed to pure colourless distilled water.



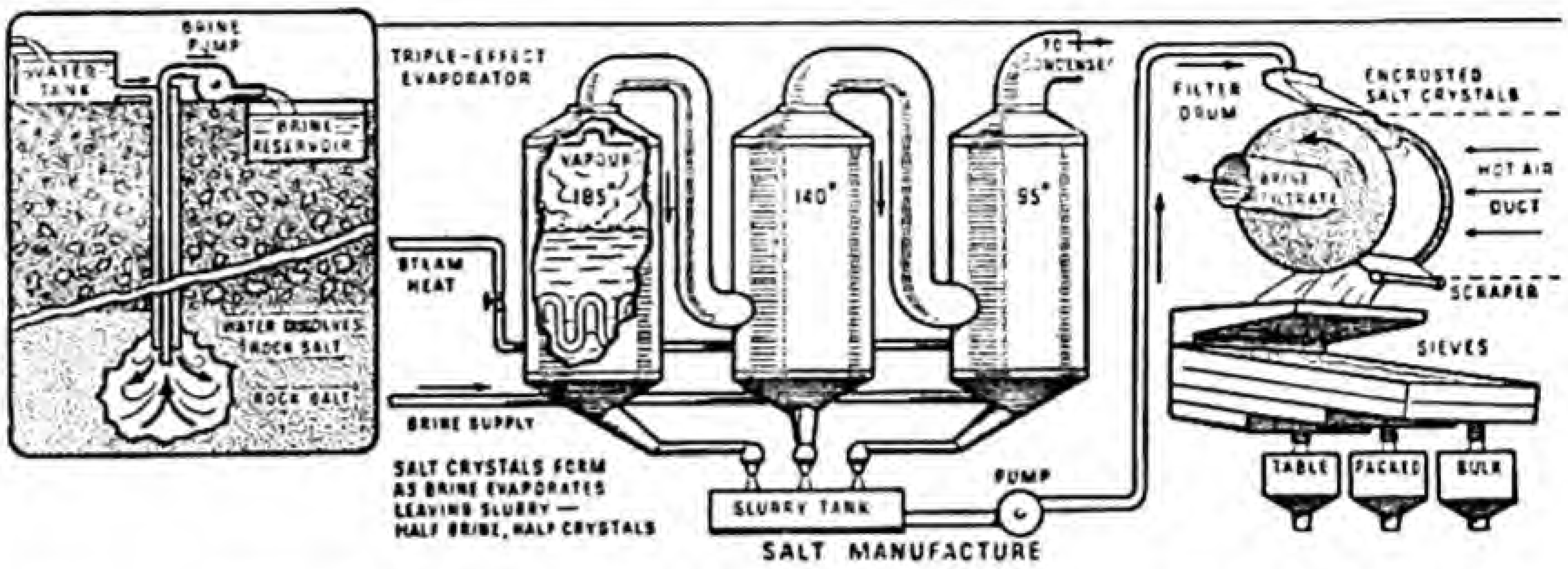
3. A method of distilling sea water for drinking. In this type of fresh-water producer, the sea water is pumped into the apparatus by the lifeboat's bilge pump and heated. The vapour, which is now free from salt, is cooled in the condenser and is converted into water which is fit for drinking.



4. Distillation can also be used to separate two or more liquids which are mixed together. When such a mixture is carefully heated, the liquid with the lowest boiling point will commence to evaporate first. The vapour is led away and condensed and the substance with the lowest boiling point is recovered. By continuing heating the temperature of the liquid will rise until it reaches the boiling point of the second liquid, which in turn is led off and condensed. This process can be used to separate a mixture of several liquids having different boiling points and is used in the primary distillation of crude mineral oil into gasoline for petrol manufacture, paraffin and various oils.

Crystallization

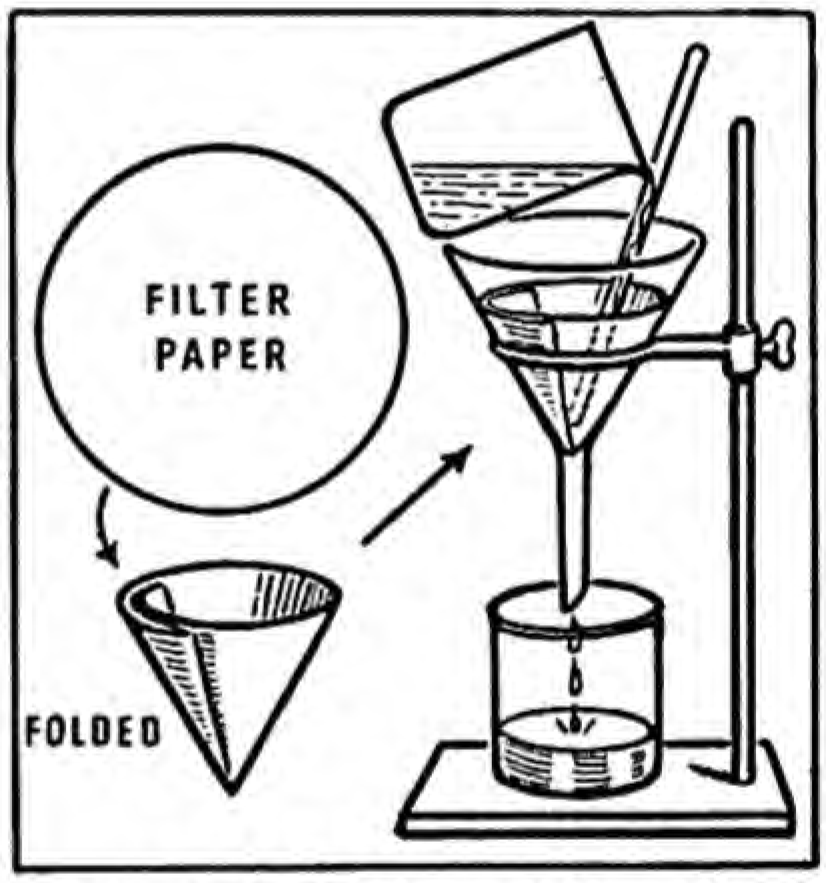
5. If a substance is dissolved and the mother liquid (solution) is then concentrated by evaporation until sufficiently strong, crystals will form on cooling. When cooling of the mother liquid is rapid, small crystals are formed, but much larger crystals can be grown by allowing cooling to take place slowly. Different substances have different saturation temperatures—the temperature at which they crystallise out of solution—and it is possible to split up a substance into its constituents by a process of fractional crystallisation. For example, by controlling the rate of cooling, several different substances in crystal form can be got from a solution of rock salt.



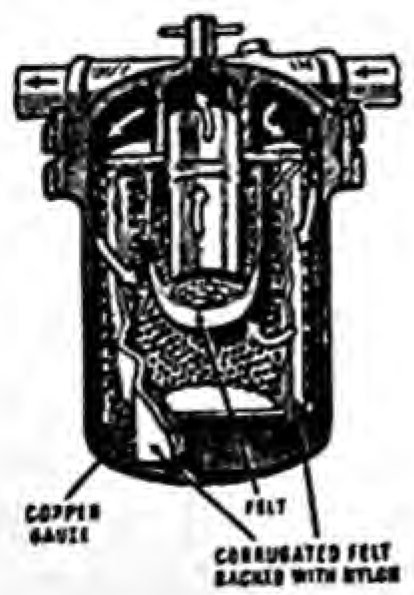
6. A salt well (*left*). Water is forced down the outer pipe and the saturated solution of brine obtained is pumped to the surface up the inner pipe, the salt being recovered by evaporation. 7. After the brine has been filtered to remove impurities, it is evaporated in the "triple-effect" evaporator (*right*), consisting of three vessels, through which the vapour passes in turn. Salt crystals are formed and are drawn off in the form of a slurry. The slurry is then passed over a rotating drum covered with fine mesh. Hot air is forced through the slurry and dries it until it forms a cake of salt, which is then removed from the drum by scraper knives. It is then sieved to grade it into the finest table salt, a less fine crystal and the largest crystals for bulk supplies.

Filtration

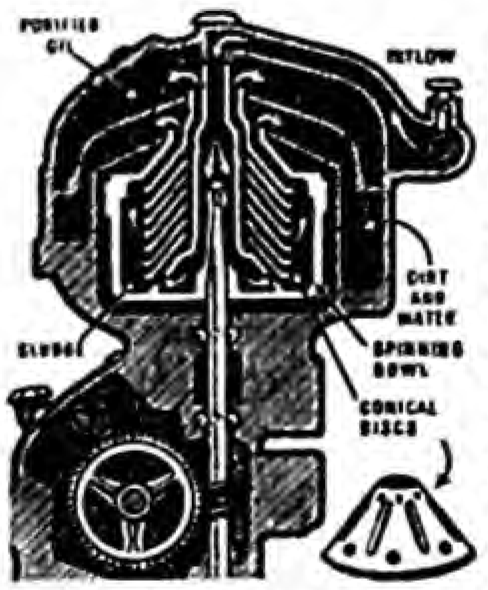
8. Filtration consists of passing a mixture of solids and liquids through a finely porous substance, e.g. paper or porcelain, which will hold back the solids and let the liquids pass through. Filtering does not remove dissolved substances or particles that are small enough to pass through the small openings of the filtering material, and there are some kind of bacteria which cannot be removed by filtration. In purifying drinking water, it is possible to get rid of most or all the harmful bacteria present by adding a substance to the water to which the bacteria will stick and thus be held back by filter.



9. Filtration in the laboratory is done with a circular piece of porous paper which is folded in the shape of a cone and placed inside a funnel. The liquid to be filtered is poured into the cone, usually down a glass rod to prevent splashing.



10. Fuel oil to be used in internal-combustion engines must be pure and free from all harmful particles of foreign matter. For fuel oil in diesel engines, very fine filtration is required because even small particles will cause wear in the injectors. The fuel filter illustrated filters the fuel in three stages. The fuel, entering the filter on the left, passes first through a cylinder of copper gauze, a second element of felt with a backing of nylon to hold back any loose fibres of felt and then passes through a further felt layer which is shaped like a miniature inverted top hat.



11. Heavy-grade fuels used on oil-fired ships have their impurities removed by a form of filter or separator which employs centrifugal force. Just as gravity causes sediment to settle to the bottom of a fluid, centrifugal force separates sediment more rapidly—but in a horizontal direction. As the fuel is rotated rapidly in the separator, the heavier particles slide along the under sides of the conical discs until they reach the sludge space while the lighter part—pure oil—tends to move towards the centre of the bowl following the upper sides of the discs.

some are metals like copper, lead, tin, aluminium, silver, which have the qualities we expect metals to have; and others are metals like sodium, potassium and calcium which, because they have a great attraction for oxygen, behave very oddly when they have been extracted.

Each of these main "ingredients" have one thing in common. However much trouble is taken they cannot be made to break down any more. No chemical reaction can make mercury split into two different substances, though it will add to itself others to make many new substances of the sort known as compounds. Substances that cannot be divided further by chemical means, are called ELEMENTS. There is a list of the best known ones at the top of the page.

The behaviour of elements and compounds is now defined in the three laws set out on the right.

Put simply, the first means that the recipe for Mercuric Oxide is always 201 parts of Mercury to 16 parts of Oxygen, and that you cannot make Mercuric Oxide except with those proportions.

It can be seen that in the "recipes" for the different compounds of Iron the amounts of Oxygen do vary but only in a simple ratio to one another:

Ferrous Oxide 56 parts of iron 16 parts of oxygen
Haematite 112 parts of Iron plus 48 parts of Oxygen
Magnetite 168 parts of Iron plus 64 parts of Oxygen
In fact, they could be shown as
Ferrous Oxide 1 part of Iron plus 1 part of Oxygen
Haematite 2 parts of Iron plus 3 parts of Oxygen
Magnetite 3 parts of Iron plus 4 parts of Oxygen
All parts by weight.

This is an example of the second law.

The amounts of elements used in different compounds go up in steps. You could say the "recipes" containing Iron always use "packets" of Iron which are 56 parts by weight. Recipes for

THE ELEMENTS

Name	Latin	Abbrev.	Name	Latin	Abbrev.	Name	Latin	Abbrev.
ALUMINIUM		Al	HELIUM		He	RADON		Rn
ANTIMONY	(Stibium)	Sb	HOLMIUM		Ho	RHODIUM		Rh
ARGON		A	HYDROGEN		H	RUBIDIUM		Rb
ARSENIC		As	INDIUM		In	RUTHENIUM		Ru
BARIUM		Ba	IODINE		I	SAMARIUM		Sm
BERYLLIUM		Be	IRIDIUM		Ir	SCANDIUM		Sc
BISMUTH		Bi	IRON	(Ferrum)	Fe	SELENIUM		Se
BORON		B	KRYPTON		Kr	SILICON		Si
BROMINE		Br	LANTHANUM		La	SILVER	(Argentum)	Ag
CADMIUM		Cd	LEAD	(Plumbum)	Pb	SODIUM	(Natrum)	Na
CALCIUM		Ca	LITHIUM		Li	STRONTIUM		Sr
CARBON		C	LUTECIUM		Lu	SULPHUR		S
CERIUM		Ce	MAGNESIUM		Mg	TANTLAUM		Ta
CAESIUM		Cs	MANGANESE		Mn	TELLURIUM		Te
CHLORINE		Cl	MERCURY	(Hydrargyrum)	Hg	TERBIUM		Tb
CHROMIUM		Cr	MOLYBDENUM		Mo	THALLIUM		Tl
COBALT		Co	NEODYMIUM		Nd	THORIUM		Th
COLUMBIUM		Cb	NEON		Ne	THULIUM		Tm
COPPER	(Cuprum)	Cu	NICKEL		Ni	TIN	(Stannum)	Sn
DYSPROSIUM		Dy	NITROGEN		N	TITANIUM		Ti
ERBIUM		Er	OSMIUM		Os	TUNGSTEN	(Wolfram)	W
EUROPIUM		Eu	OXYGEN		O	URANIUM		U
FLUORINE		F	PALLADIUM		Pd	VANADIUM		V
GADOLINIUM		Gd	PHOSPHORUS		P	XENON		Xe
GALLIUM		Ga	PLATINUM		Pt	YTTERBIUM		Yb
GERMANIUM		Ge	POTASSIUM	(Kalium)	K	YTTRIUM		Y
GOLD	(Aurum)	Au	PRASEODYMIUM		Pr	ZINC		Zn
HAFNIUM		Hf	RADIUM		Ra	ZIRCONIUM		Zr

Oxygen-containing substances, always use "packets" of Oxygen which are 16 parts by weight.

Until Dalton thought out his brilliant theory of atoms, no one could clearly explain what was happening during chemical reactions and what the accompanying weight changes meant.

An element combines in these "steps" of parts-by-weight when it joins with a third element.

Ferrous Sulphide—56 parts of Iron plus 32 parts of sulphur $\frac{S}{O} : \frac{2}{1}$
Ferrous Oxide—56 parts of Iron plus 16 parts of Oxygen
Sulphur Dioxide—32 parts of Sulphur plus 32 parts of Oxgyen $\frac{S}{O} : \frac{1}{1}$

Sulphur combines with oxygen in sulphur dioxide in a ratio of 1 part to 1 part. Sulphur combines with iron in ferrous sulphide in a ratio of 1 part to 1 part. And when oxygen combines with iron in ferrous oxide, it is in a ratio of 1 part to half a part of the quantities in the first two recipes.

This is an example of the third law. If the proportions of the elements in a compound must always be the same and if there is a smallest possible piece of the compound, then the combined weights of the elements will be in the ratio of the weights of their "packets" or smallest possible pieces. The smallest possible piece of an element Dalton named an Atom. The smallest possible piece of a compound he called a molecule. The molecule itself must be described by a recipe worked not in pounds or grams or milligrams but in atoms. You cannot have a fraction of an atom in a compound, because, by definition, an atom cannot be sub-divided. How to reckon the weights of atoms, we will consider very soon.

THE LAW OF CONSTANT PROPORTIONS

In any compound substance, formed or decomposed, the proportion by weight of the constituent elements is the same.

THE LAW OF MULTIPLE PROPORTIONS

When two elements combine to form more than one compound, the varying weights of the second element, combining with a constant weight of the first are in a simple ratio.

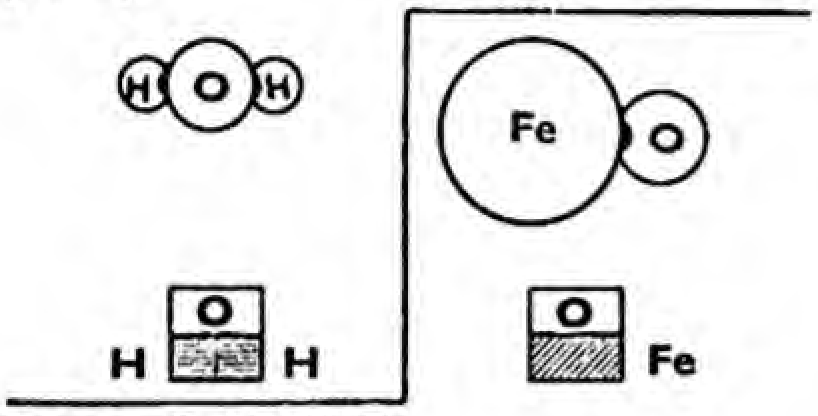
THE LAW OF RECIPROCAL PROPORTIONS

If element A combines with element B and also with element C, then if B and C do combine together the proportions in which they do so will be simply related to the weight of each that combines with a constant weight of A.

Writing the Recipes

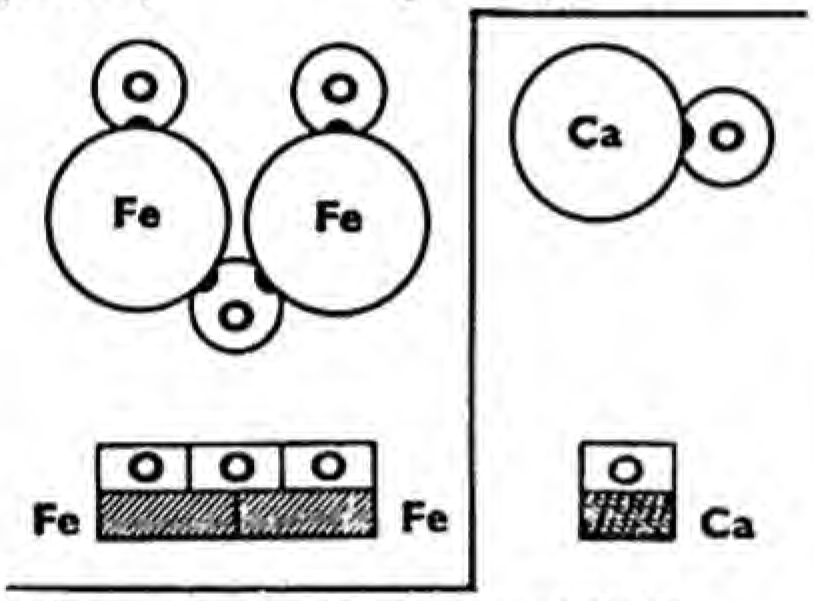
Parts by weight with diagrams of atoms of different elements in single molecules of each compound and valencies of elements as block diagrams.

Hydrogen Monoxide **(Water)** H_2O
Hydrogen 2 — **Oxygen 16**
(1 × 2) — (16 × 1)



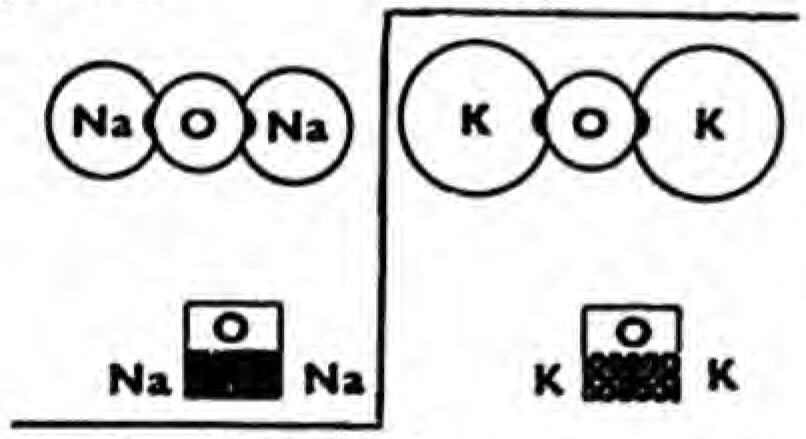
Ferrous Oxide FeO
Iron 56 — **Oxygen 16**
(56 × 1) — (16 × 1)

Ferric Oxide **(Jewellers' Rouge)** Fe_2O_3
Iron 112 — **Oxygen 48**
(56 × 2) — (16 × 3)



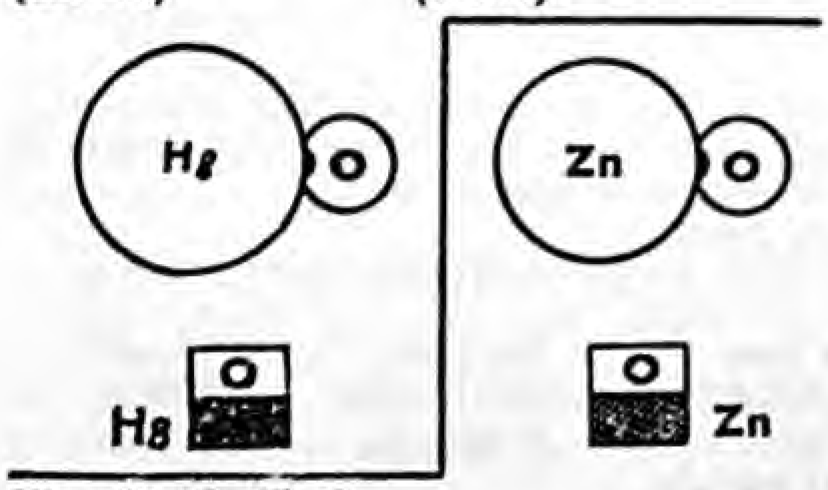
Calcium Oxide **(Quicklime)** CaO
Calcium 40 — **Oxygen 16**
(40 × 1) — (16 × 1)

Sodium Oxide Na_2O
Sodium 46 — **Oxygen 16**
(23 × 2) — (16 × 1)



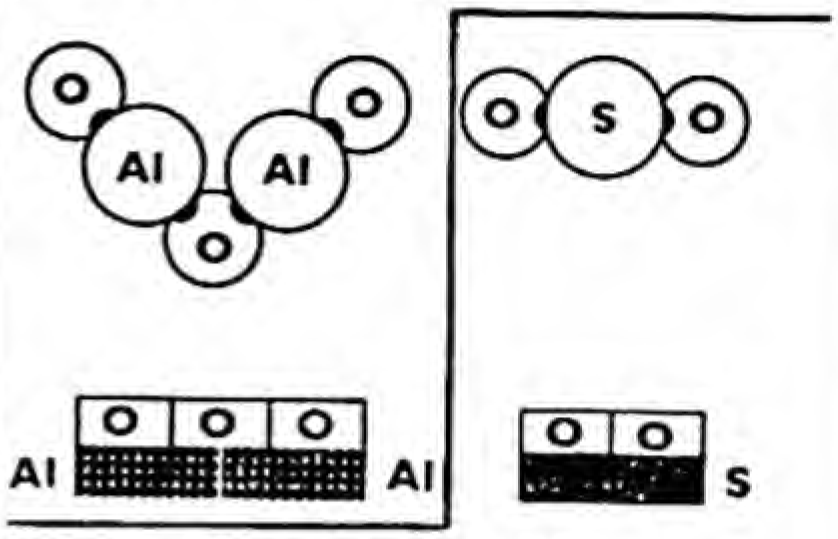
Potassium Oxide K_2O
Potassium 78 — **Oxygen 16**
(39 × 2) — (16 × 1)

Mercuric Oxide HgO
Mercury 201 — **Oxygen 16**
(201 × 1) — (16 × 1)



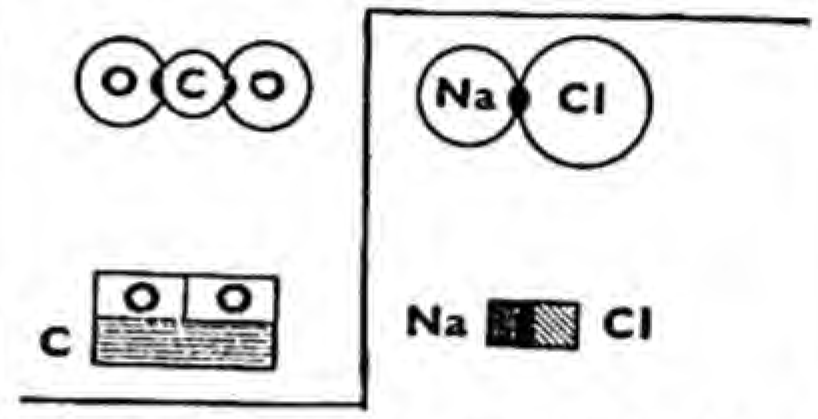
Zinc Oxide ZnO
Zinc 65 — **Oxygen 16**
(65 × 1) — (16 × 1)

Aluminium Oxide Al_2O_3
Aluminium 54 — **Oxygen 48**
(27 × 2) — (16 × 3)



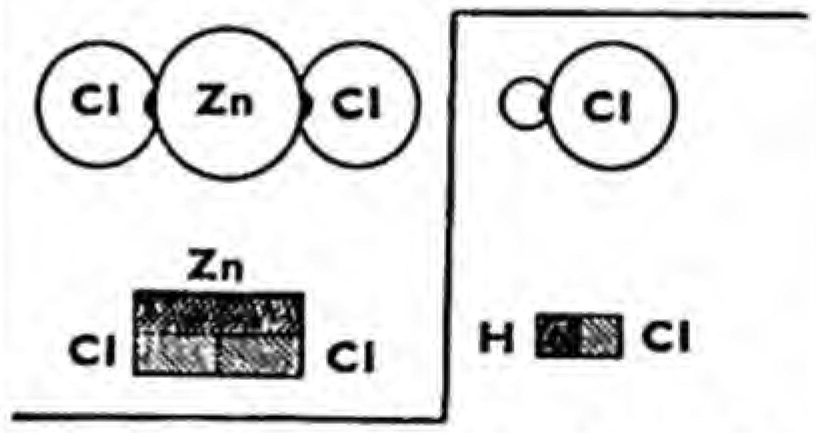
Sulphur Dioxide **(a gas)** SO_2
Sulphur 32 — **Oxygen 32**
(32 × 1) — (16 × 2)

Carbon Dioxide **(a gas)** CO_2
Carbon 12 — **Oxygen 32**
(12 × 1) — (16 × 2)



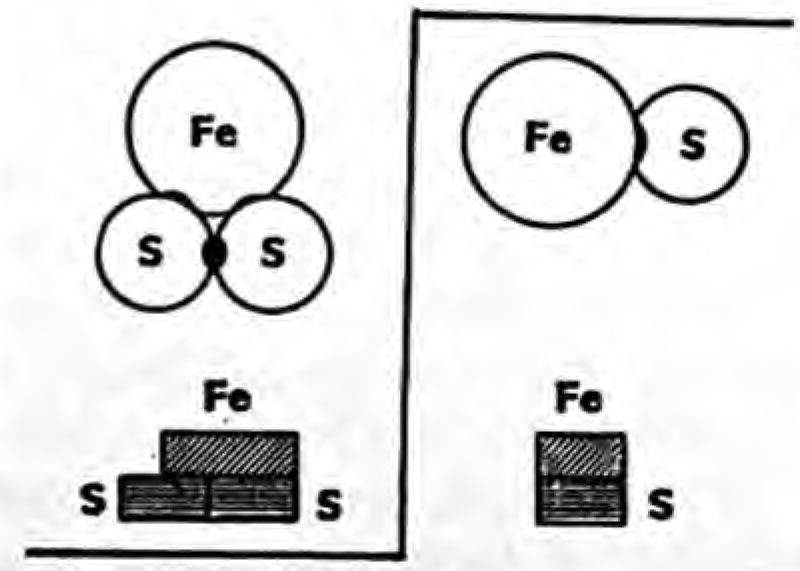
Sodium Chloride **(Table Salt)** $NaCl$
Sodium 23 — **Chlorine** $35\frac{1}{2}$
(23 × 1) — ($35\frac{1}{2}$ × 1)

Zinc Chloride $ZnCl_2$
Zinc 65 — **Chlorine 71**
(65 × 1) — ($35\frac{1}{2}$ × 2)



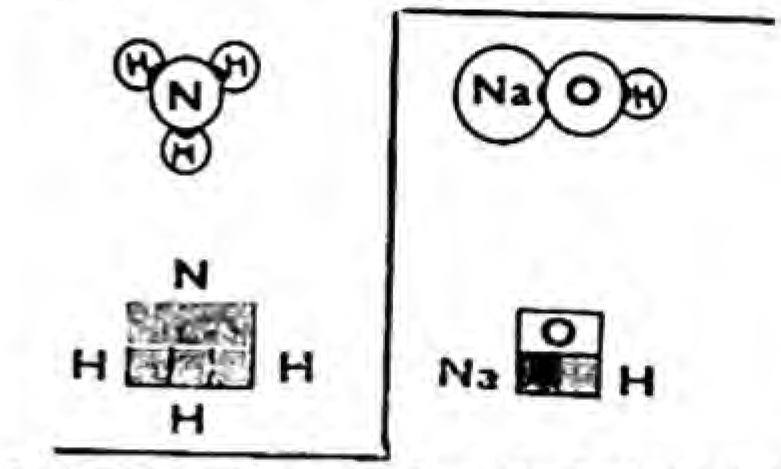
Hydrogen Chloride **(Hydrochloric Acid Gas)** HCl
Hydrogen 1 — **Chlorine** $35\frac{1}{2}$
(1 × 1) — ($35\frac{1}{2}$ × 1)

Iron Pyrites **("Fools' gold", the sulphide of Iron)** FeS_2
Iron 56 — **Sulphur 64**
(56 × 1) — (32 × 2)



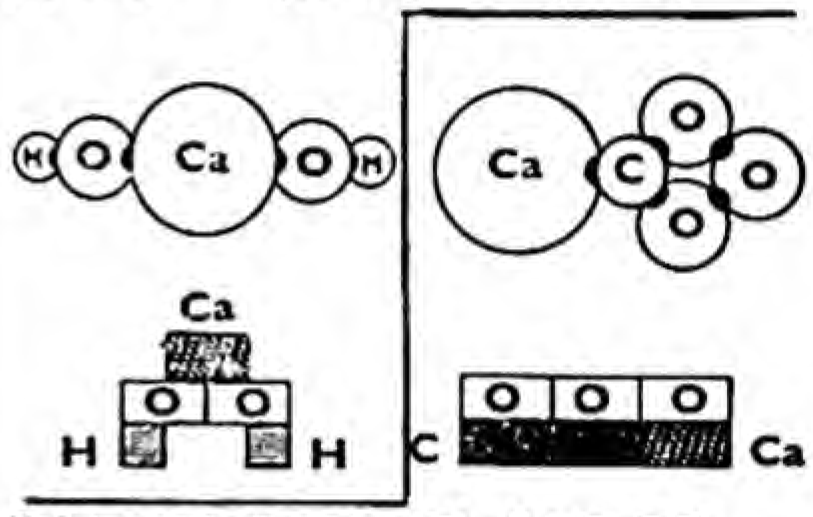
Ferrous Sulphide FeS
Iron 56 — **Sulphur 32**
(56 × 1) — (32 × 1)

Ammonia **(a gas)** NH_3
Nitrogen 14 — **Hydrogen 3**
(14 × 1) — (1 × 3)



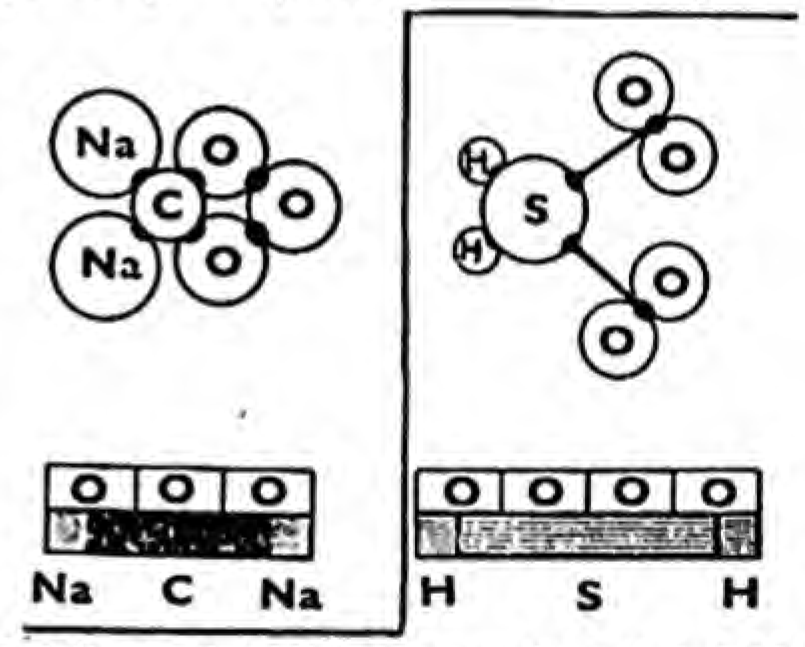
Sodium Hydroxide **(Caustic Soda)** $NaOH$
Sodium 23 — **Oxygen 16** — **Hydrogen 1**
(23 × 1) — (16 × 1) — (1 × 1)

Calcium Hydroxide **(Slaked Lime)** $Ca(OH)_2$
Calcium 40 — **Oxygen 32** — **Hydrogen 2**
(40 × 1) — (16 × 2) — (1 × 2)



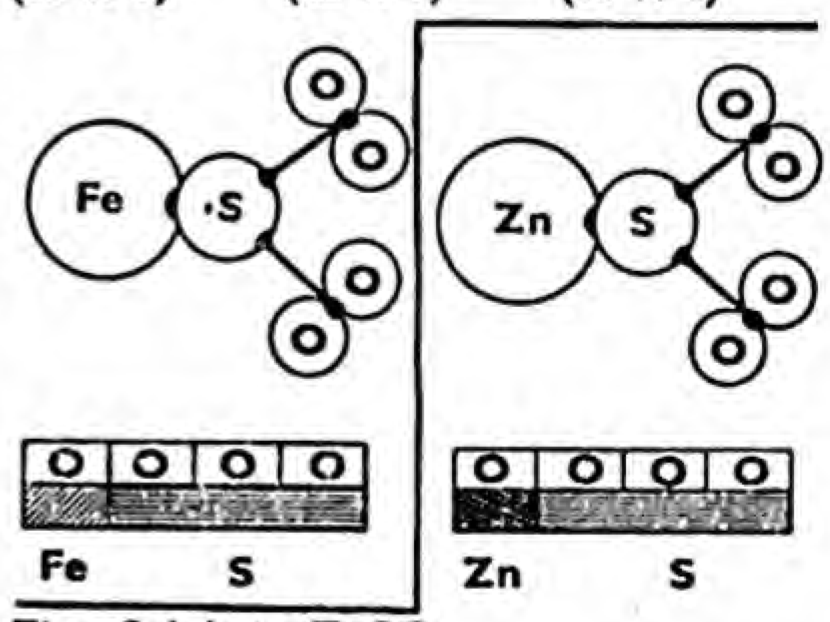
Calcium Carbonate **(Chalk)** $CaCO_3$
Calcium 40 — **Carbon 12** — **Oxygen 48**
(40 × 1) — (12 × 1) — (16 × 3)

Sodium Carbonate **(Washing Soda)** Na_2CO_3
Sodium 46 — **Carbon 12** — **Oxygen 48**
(23 × 2) — (12 × 1) — (16 × 3)



Sulphuric Acid **(Hydrogen Sulphate)** H_2SO_4
Hydrogen 2 — **Sulphur 32** — **Oxygen 64**
(1 × 2) — (32 × 1) — (16 × 4)

Ferrous Sulphate **(Green Vitriol)** $FeSO_4$
Iron 56 — **Sulphur 32** — **Oxygen 64**
(56 × 1) — (32 × 1) — (16 × 4)

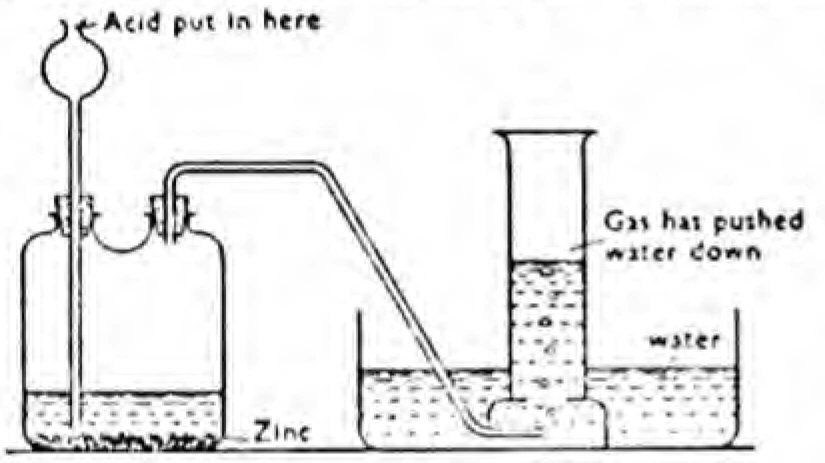


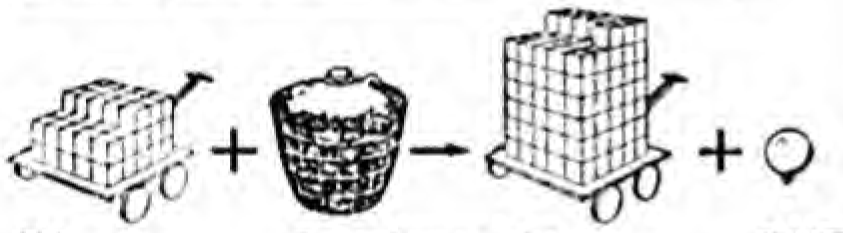
Zinc Sulphate $ZnSO_4$
Zinc 65 — **Sulphur 32** — **Oxygen 64**
(65 × 1) — (32 × 1) — (16 × 4)

The Lightest Element that is the Yardstick for All the Others

One of the compounds of iron has the form of green crystals which are found in nature and known as Crystals of Green Vitriol. Its chemical name is Ferrous Sulphate. If Ferrous Sulphate is roasted, it gives off thick white fumes, and when these condense in water, they produce a colourless liquid that will burn flesh or even clothing. It turns Litmus Paper red. It is classed as an Acid. Its name is Sulphuric Acid.

Sulphuric acid when suitably diluted, acts on many metals with a good deal of fizzing. It combines with them to make metallic salts and releases a gas—Hydrogen.

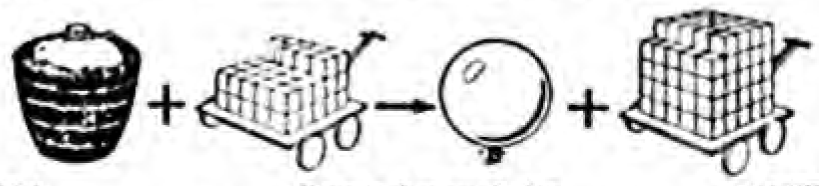




IN		Parts by weight		OUT
65 parts of ZINC	+	98 parts of SULPHURIC ACID →	161 parts of ZINC SULPHATE +	2 parts of HYDROGEN

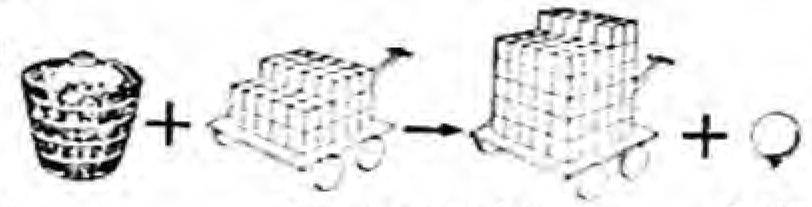
The gas is very light. Under pressure, it will fill a toy balloon, which duly tied, will rise rapidly. Obviously Hydrogen is lighter than air. Soap lather smeared on to a feed tube from the jar of Hydrogen will form soap bubbles as the gas blows out. If one is touched with a lighted match as it rises out of reach it will explode with a loud "pop" and burn.

Another acid can be made by putting sulphuric acid on ordinary table salt (chemical name: sodium chloride).



IN		Parts by weight		OUT
98 parts of SULPHURIC ACID	+	58½ parts of SODIUM CHLORIDE (Table Salt) →	36½ parts of a gas HYDROGEN CHLORIDE (Hydrochloric Acid Gas) +	120 parts of a compound SODIUM BISULPHATE

This gas easily dissolves in water and the solution is called Hydrochloric Acid. This acid also will react with Zinc, using the same apparatus as before.



IN		Parts by weight		OUT
72 parts of HYDROCHLORIC ACID	+	65 parts of ZINC →	135 parts of ZINC CHLORIDE +	2 parts of HYDROGEN

To dissolve the same amount of Zinc as was dissolved in sulphuric acid, we need a different amount of this acid, but we obtain the same amount of Hydrogen—and it really is Hydrogen. It answers exactly the same tests as the gas given off by Sulphuric Acid and Zinc.

Even with the few compounds mentioned so far, the fact is beginning to show up that each element combines with others, or changes places in definite "packets". Though sometimes several "packets" of an element get used in a compound. Iron, if you glance back, was obtained in packets of 56, 112, or 168, while Oxygen has so far appeared in packets of 16, 32, and 48. Zinc in packets of 65—all parts by weight. Moreover, 65 parts by weight of zinc set free 2 parts by weight of hydrogen, regardless of whether it is sulphuric or hydrochloric acid in which they are dissolved. Now, to settle the relative size of the "packets" of each element *which will change places*, there must be some yardstick, and the most obvious one is the one that was chosen, the lightest element, Hydrogen.

The recipes on page 125 show that the elements each have a basic "packet" which relates to the basic "packet" of Hydrogen. And they show as well that, according to what other elements it combines with, so the number of packets of the reacting element may also vary.

The combining ability of an element with varying packages of other elements is called its valency.

It is normally measured as the number of hydrogen atoms the atom of the element in question can hold, or can replace in a compound.

Equivalent Weights

The equivalent weight of an element (or compound) is the number of parts by weight of the element (or compound) that combine with or displace ONE OF THE SAME PARTS by weight of HYDROGEN (or the equivalent weight of OXYGEN).

Here are reports on the reactions of:

Sulphuric Acid and Zinc

65 parts ZINC	98 parts → SULPHURIC ACID	161 parts ZINC SULPHATE	2 parts HYDROGEN

Sulphuric Acid and Iron

56 parts IRON	98 parts → SULPHURIC ACID	152 parts FERROUS SULPHATE	2 parts HYDROGEN

You can see that 65 parts of Zinc released 2 parts of Hydrogen. So a weight of Zinc that is equivalent to one weight of Hydrogen weighs 32½ times as much.

The Equivalent Weight of } ZINC is 32½
IRON is 28 $\left(\text{i.e. } \frac{56}{2}\right)$

And in Ferrous Oxide (recipe 56 parts of Iron to 16 parts of Oxygen) this must mean that

The Equivalent Weight of } OXYGEN is 8 $\left(\text{i.e. } \frac{56}{2} : \frac{16}{2}\right)$

Since this is the weight of Oxygen that combines with the equivalent weight of Iron $\left(\frac{56}{2}\right)$.

In Sulphur Dioxide (recipe 32 parts of Sulphur to 32 parts of Oxygen), because we know the equivalent weight of Oxygen we can work out

The Equivalent Weight of } SULPHUR is 16 { The Sulphur combines with a double packet of Oxygen. (32 Sulphur plus 16x2 Oxygen) Eq. Wt. of Sulphur—twice that of Oxygen 8x2=16

If we didn't already know the Eq. Wt. of Iron the recipe for Ferrous Sulphate would give it:

32 Sulphur: 56 Iron

Eq. Wt. 16 (32/2): Eq. Wt. 28 (56/2)

This cross-checks the previous calculation. All these cases are where two packets of Hydrogen combine with one of the other elements.

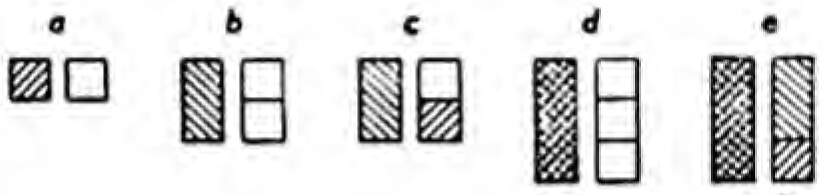
The recipe for Hydrochloric Acid is

1 part HYDROGEN (1 packet)	35½ parts → CHLORINE (1 packet)	36½ parts HYDROCHLORIC ACID

So the equivalent weight of CHLORINE is 35½.

Valency

VALENCY. The Latin word is *Valere*, to bestrong. The "strength" divides the elements into classes. The elements of Class One have a valency of One:—Hydrogen and Chlorine belong here. One packet of each can join to make Hydrochloric Acid. But to combine with one packet of Oxygen which is in Valency Class Two, there must be two packets of Hydrogen ($H_2 + O \rightarrow H_2O$) Water.



a	b	c
Both Valency 1	Valency 2 Element needs two Valency 1 atoms to combine with it	Valency 2 Element needs one atom each of two Valency 1 elements

d	e
Valency 3 *or* Element needs three atoms of Valency 1 element to combine with it	any combination that will make up three

and so on up to Valency 7.

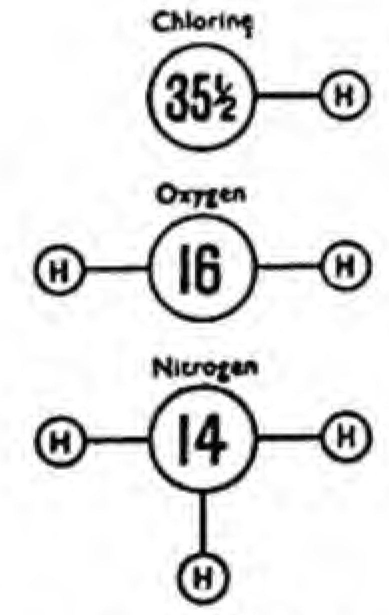
The models of compounds will help to make this clear. Valency does not depend on size or weight of the element, it is its "strength of joining" (combining capacity.)

If you look back at the recipes of the compounds that have been mentioned you will see that valency is the reason for the varying weights of the same element in different compounds. These never vary from being the basic atomic weight multiplied by 1, 2, 3, 4, 5 or 6.

Once you know the valency of all the elements you can work out for yourself the formula for a chemical compound, provided you know its molecular weight, for valency tells you the number of atoms of one element that must combine with one atom of the other, and their total weights must add up to the molecular weight. Sometimes more than one set of atoms go to make up a molecule. e.g. Methane: H is Valency 1, Carbon is Valency 4, so the Formula must be CH_4; four atoms of H to one of C. And the recipe will be:

HYDROGEN (At. wt. 1 x 4) 4 parts by weight + CARBON (At. wt. 12 x 1) 12 parts by weight → CH_4 METHANE 16 parts by weight

The molecular weight of Hydrogen Fluoride is 40 yet the atomic weight of Hydrogen is 1 and of Fluorine 19, so HF would equal 20. This means the formula must be written $(HF)_2$ or H_2F_2—there are two sets of atoms in the molecule. In the same way it explains why we sometimes have Hydrogen in the recipes as two parts (72 parts Hydrochloric Acid plus 65 parts of Zinc gives 135 parts Zinc Chloride plus 2 parts of Hydrogen). Once the valency of an element is known, its Atomic Weight (i.e. its weight as against the weight of one Hydrogen atom) can be worked out since it must follow that:



	Equivalent weight		Atomic weight / Valency
Chlorine	35½	=	$\frac{35\frac{1}{2}}{1}$
Oxygen	8	=	$\frac{16}{2}$
Nitrogen	4·7	=	$\frac{14}{3}$

Equivalent Weight × Valency = Atomic Weight.

Oxygen (equivalent weight 8, valency 2) = 16 Atomic Weight.

Zinc (equivalent weight 32½, valency 2) = 65 Atomic Weight.

Chlorine (equivalent weight 35½, valency 1) = 35½ Atomic Weight.

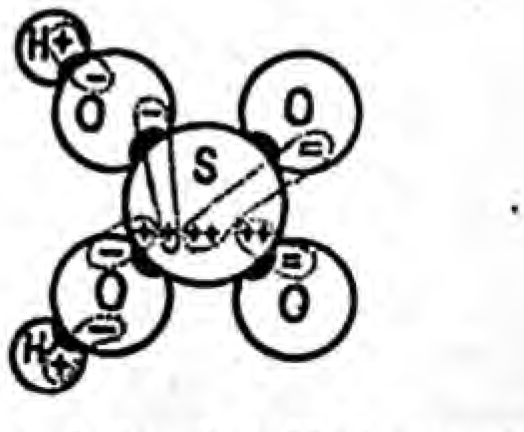
In other words we are recognising that one packet of Zinc in Sulphuric Acid releases two packets of Hydrogen, and in their smallest form these packets are single atoms of the elements.

One atom of Zinc (65 times heavier than a single Hydrogen atom) releases two atoms of Hydrogen.

If an element joins with something that is already a group made of the atoms of several elements (for instance sulphuric acid—which behaves as if it were composed of two main parts—called RADICALS—that act as single substances, H_2 Hydrogen, and SO_4 that makes the metal salt) each part of the formula is treated as if it were an element when working out the valency: i.e. Radicals have valencies.

The reason the SO_4 Radical moves as if it is an element is that the four atoms of Oxygen, each with 2 valencies combined with the 6 Valencies of the one atom of Sulphur, give SO_4, a final Valency of two, i.e. it can hold the two Hyrodgen atoms.

Each molecule of H_2SO_4 is diagrammatically like this:



Three of these, losing their Hydrogen atoms, need a total of 6 valencies to balance them.

GAS LAWS OF CHEMISTRY

GAY-LASSAC'S LAW OF COMBINING VOLUMES

Gases, when combining, do so in volumes that are in a simple ratio to each other, and if the result of the combination is a gas, then the volume of that too will be in a simple ratio to the volumes of the original gases. E.g. 1 c.c. of Hydrogen plus 1 c.c. of Chlorine in a test-tube exposed to sunlight (to cause them to react) combine as 2 c.c. of Hydrochloric Acid Gas. Or 2 c.c. of Hydrogen burnt with 1 c.c. of Oxygen combine (at over 100°C.) as 2 c.c. of steam.

AVOGADRO'S HYPOTHESIS

Equal volumes of different gases at the same temperature and pressure contain the same number of molecules.

That is, if Avogadro was right (and the whole of modern chemistry proves that he was) the spacing of the molecules of 1 c.c. of hydrogen gas and 1 c.c. of chlorine will be the same distance apart. Yet 1,000 c.c. of hydrogen weigh about ·09 gram, while 1,000 c.c. of chlorine weigh 3·17 grams—a pretty good proof that one molecule of chlorine is as much heavier than one molecule of Hydrogen, as Equivalent Weights experiments say they are.

Approximate Weight of 1,000 *c.c.* (1 *litre*) *of some gases at* 0°C. *and* 760 *m.m.* (1 *atmosphere*) *pressure*

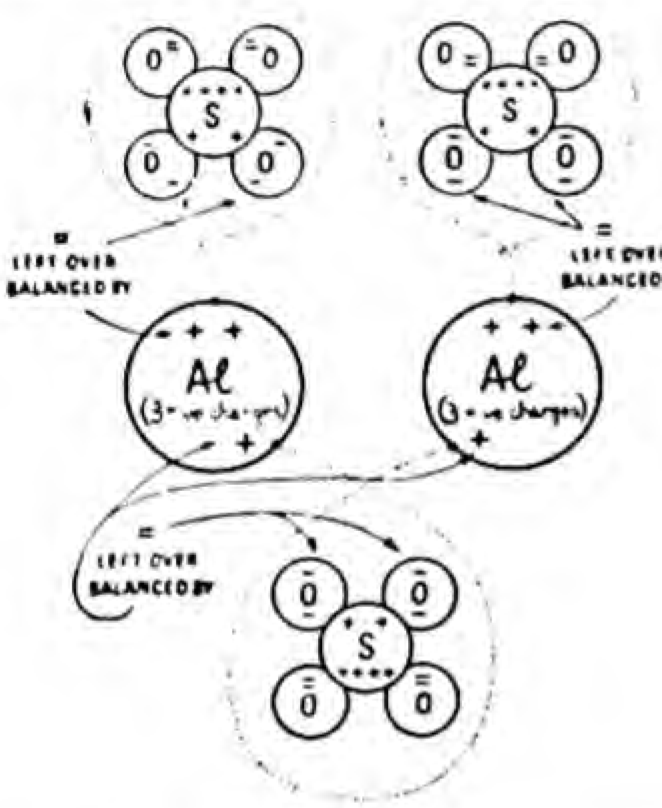
	grams
Hydrogen	·09
Oxygen	1·43
Chlorine	3·17
Hydrogen Chlorid	1·63
Carbon Dioxide	1·96
Nitrogen	1·25
Sulphur Dioxide	2·93

Note: There are certain rather complicated laws to do with the behaviour of gases under pressure that mean that these figures do not exactly work out at the equivalent weights.

VALENCY 1		VALENCY 2		VALENCY 3		VALENCY 4		VALENCY 5		VALENCY 6	
Hydrogen	H^{+}	Oxygen	$O^{=}$	Boron	B	Silicon	Si	Nitrogen	N	Sulphur	S
Lithium	Li	Beryllium	Be	Aluminium	Al^{+++}	Titanium	Ti	Phosphorus	P	Chromium	Cr
Sodium	Na^{+}	Magnesium	Mg^{++}	Scandium	Sc	Tin	Sn^{++++}	Vanadium	V	Selenium	Se
Potassium	K^{+}	Calcium	Ca^{++}	Gallium	Ga	Lead	Pb	Arsenic	As	Molybdenum	Mo
Copper	Cu	Zinc	Zn^{++}	Gold	Au	Nitrogen	N	Antimony	Sb	Tellurium	Te
Rubidium	Rb	Strontium	Sr	Nitrogen	N	Sulphur	S	Bismuth	Bi	Tungsten	W
Silver	Ag^{+}	Cadmium	Cd	Phosphorus	P	Platinum	Pt	Chlorine	Cl	Uranium	U
Caesium	Cs	Barium	Ba^{++}	Arsenic	As	Carbon	C			Manganese	Mn
Gold	Au	Mercury	Hg^{++}	Antimony	Sb^{+++}	Chlorine	Cl				
Fluorine	F^{-}	Tin	Sn^{++}	Iron	Fe^{+++}	Manganese	Mn				
Chlorine	Cl^{-}	Lead	Pb^{++}	Bismuth	Bi^{+++}	Selenium	Se				
Bromine	Br^{-}	Iron	Fe^{++}	Manganese	Mn	Tellurium	Te				
Iodine	I^{-}	Nitrogen	N	Chromium	Cr^{+++}	Tungsten	W				
Nitrogen	N	Platinum	Pt								
Mercury	Hg	Copper	Cu^{++}								
		Sulphur	S								
		Carbon	C								
		Manganese	Mn^{++}								

NOTE: The plus and minus signs against some of the elements' symbols indicate the positive or negative charge of the element's *ION*. That is, when the element combines with another to form a compound the atom of the element may gain or lose an electron (or more than one) to the atom of the other element, so leaving it unbalanced electrically with its nucleus. It is only when in this state that the atom of an element is an Ion and has a charge.

The 3 valencies of each of 2 aluminium atoms will do this.



Certain elements in different circumstances behave with more than one valency. For example, Sulphur in H_2SO_4 has a valency of 6, at other times it has a valency of 2 or of 3.

Iron for instance forms two series of compounds, one lot of Valency 2 and the other of Valency 3.

Ferrous Oxide

IRON	+	OXYGEN	→	FERROUS OXIDE
56 parts		16 parts		72 parts
				FeO

Also $FeCl_2$ $Fe(OH)_2$ $FeSO_4$.

		Class
VALENCY:	Oxygen	$2 \times 1 = 2$
	Iron	$2 \times 1 = 2$

Ferric Oxide (Jewellers' Rouge)

IRON	+	OXYGEN	→	FERRIC OXIDE
112 parts		48 parts		160 parts
				Fe_2O_3

		Class
VALENCY:	Oxygen	$2 \times 3 = 6$
	Iron	$3 \times 2 = 6$

Also $FeCl_3$ $Fe(OH)_3$, $Fe_2(SO_4)_3$.

The names given are Ferrous for the Valency 2 compounds and Ferric for the Valency 3 compounds. The list of valencies shows that several of the chemical elements can have more than one valency.

Some compounds exist in which there is a "spare strength" of valency. One of the elements (say of Valency 2) is only holding one atom of Valency 1, so it has spare combining capacity, and such compounds are usually unstable, that is, they are very ready to join with extra elements and make up the balance, becoming fresh compounds in the process.

THE ATOMIC WEIGHTS OF THE ELEMENTS

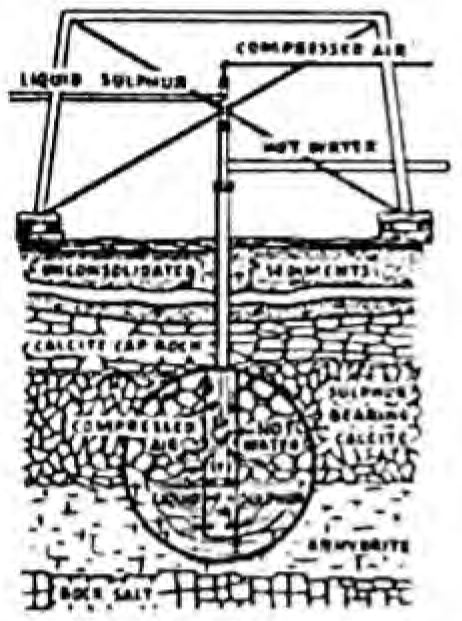
Because Oxygen, unlike Hydrogen, combines so easily with most other elements (it is easier to find the equivalent weights for oxygen for each element), the exact Atomic Weights have been worked out on the basis of Oxygen = 16. Hydrogen then becomes, not exactly 1, but 1.008 and the other elements vary accordingly. For most purposes it is quite all right to use the round numbers as in all the recipes in this article.

Element	*Symbol*	*Wt.At.*	*Element*	*Symbol*	*At. Wt.*	*Element*	*Symbol*	*At. Wt.*
Hydrogen	H	1.008	Sellenium	Se	78.96	Dysprosium	Dy	162.46
Helium	He	4.003	Bromine	Br	79.916	Holmium	Ho	164.94
Lithium	Li	6.94	Krypton	Kr	83.7	Erbium	Er	167.2
Beryllium	Be	9.013	Rubidium	Rb	85.48	Thulium	Tm	169.4
Boron	B	10.82	Strontium	Sr	87.63	Ytterbium	Yb	173.04
Carbon	C	12.010	Yttrium	Y	88.92	Lutetium	Lu	174.99
Nitrogen	N	14.008	Zirconium	Zr	91.22	Hafnium	Hf	178.6
Oxygen	O	16.00	Niobium	Nb	92.91	Tantalum	Ta	180.88
Fluorine	F	19.00	Columbium	Cb	93.1	Tungsten	W	183.92
Neon	Ne	20.183	Molybdenum	Mo	95.95	Rhenium	Re	186.31
Sodium	Na	22.997	Technetium	Tc	99	Osmium	Os	190.2
Magnesium	Mg	24.32	Ruthenium	Ru	101.7	Iridium	Ir	193.1
Aluminium	Al	26.97	Rhodium	Rh	102.91	Platinum	Pt	195.23
Silicon	Si	28.06	Palladium	Pa	106.7	Gold	Au	197.2
Phosphorus	P	30.98	Silver	Ag	107.88	Mercury	Hg	200.61
Sulphur	S	32.066	Cadium	Cd	112.41	Thallium	Tl	204.39
Chlorine	Cl	35.457	Indium	In	114.76	Lead	Pb	207.21
Potassium	K	39.096	Tin	Sn	118.70	Bismuth	Bi	209.00
Argon	A	39.944	Antimony	Sb	121.76	Polonium	Po	210
Calcium	Ca	40.08	Iodine	I	126.92	Astatine	At	210
Scandium	Sc	45.10	Tellurium	Te	127.61	Radon	Rn	222
Titanium	Ti	47.90	Xenon	Xe	131.3	Francium	Fr	223
Vanadium	V	50.95	Caesium	Cs	132.91	Radium	Ra	226.05
Chromium	Cr	52.01	Barium	Ba	137.36	Actinium	Ac	227
Manganese	Mn	54.93	Lanthanum	La	138.92	Protactinium	Pa	231
Iron	Fe	55.85	Caerium	Ce	140.13	Thorium	Th	232.12
Nickel	Ni	58.69	Praseodymium	Pr	140.92	Neptunium	Np	237
Cobalt	Co	58.94	Neodymium	Nd	144.27	Uranium	U	238.07
Copper	Cu	63.54	Promethium	Pm	147	Plutonium	Pu	239
Zinc	Zn	65.38	Samarium	Sm	150.43	Americium	Am	241
Gallium	Ga	69.72	Europium	Eu	152.0	Curium	Cm	242
Germanium	Ge	72.60	Gadolinium	Gd	156.9			
Arsenic	As	74.91	Terbium	Tb	159.2			

MOLECULAR WEIGHTS

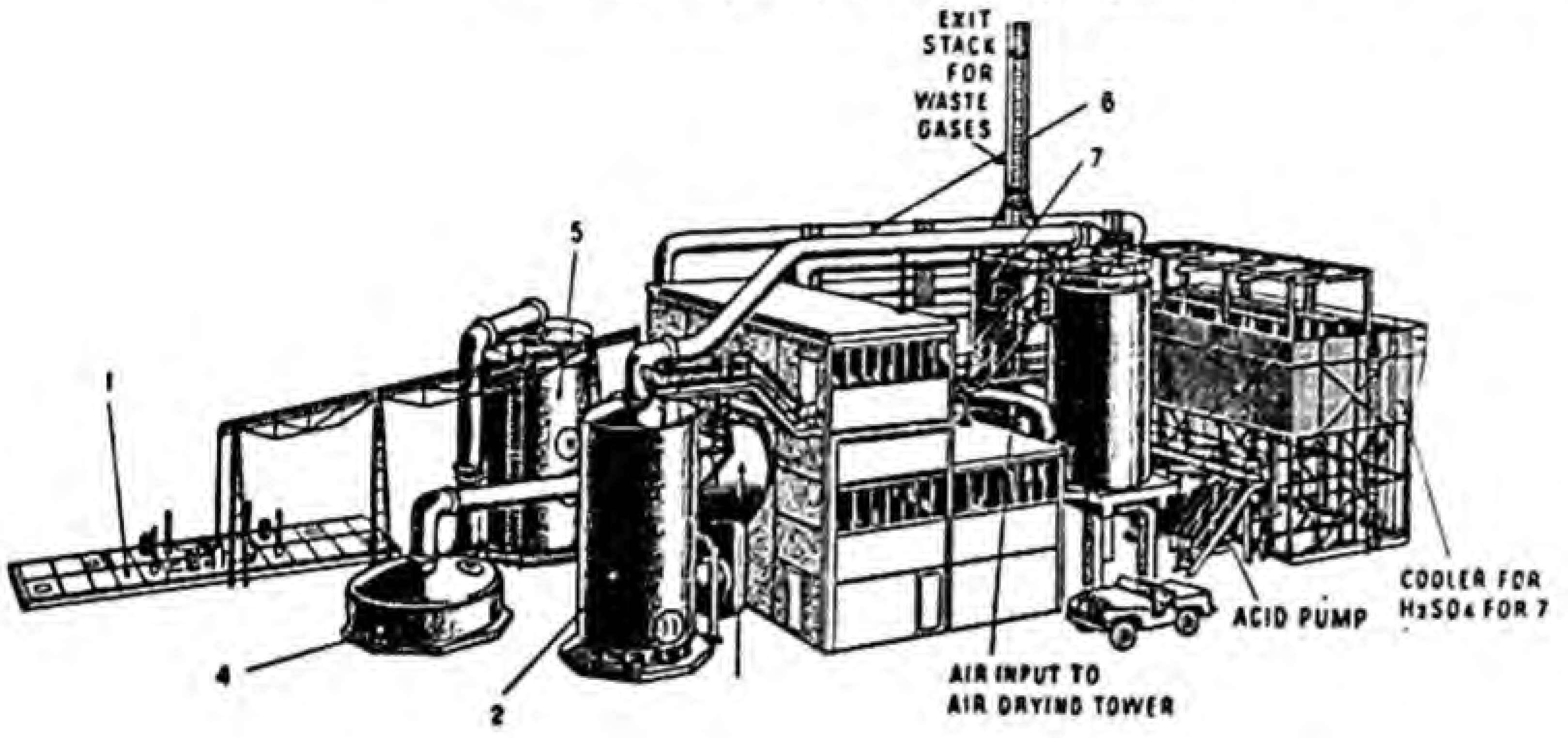
Obviously a single molecule of a compound is too tiny to be weighed, so various methods are used to calculate it from its properties. The simplest is for gases, where 22½ *litres of a gas contain the molecular weight in grams*. In other words Avogadro's Hypothesis (p. 127) says: at a given temperature and pressure the same volume of a heavy or a light gas contains the same number of molecules. It has been calculated that the number of molecules in 22½ litres (1 litre=1000 cubic centimetres) which is the volume of 32 grams of Oxygen or 2 grams of Hydrogen, is 6,060,000,000,000,000,000,000,000

Sulphur



Sulphur, which is often erupted by volcanoes, is found also in underground deposits resulting from volcanic activity of earlier ages. The chief ones are in Iceland, Italy, New Zealand, Japan, Mexico and in Texas and Louisiana in the U.S.A. Its low melting point (114°C.) enables it to be mined by pumping hot water down a borehole, and using compressed air down an inner pipe to bring the melted sulphur to the surface; on cooling it solidifies into yellow crystals in giant vats.

The greatest importance of sulphur is that sulphuric acid can be made from it. Sulphur is melted (1) and then burned in air (2); of the resultant mixture of nitrogen (N_2), oxygen (O_2) and sulphur dioxide (SO_2), the latter two (SO_2 and O_2) are filtered out (4), and then mixed in the presence of the vanadium catalyst (5). The catalyst "persuades" SO_2 to add a further atom of oxygen (oxidisation) and become sulphur trioxide (SO_3). A good deal of heat is acquired during the reaction so the SO_3 is cooled (6) before the final stage. This cannot, as one would think, be the simple dissolving of SO_3 in water, H_2O, to give H_2SO_4, sulphuric acid, for they only partially combine because the water tends to evaporate. So the SO_3 is bubbled through a tank of sulphuric acid previously manufactured (7) (absorber tower), and combines, easily producing strong H_2SO_4, which is then diluted with water to the usual strength used in numerous commercial processes. This is known as the contact (i.e. catalyst) process, and a number of other catalysts have been used before the vanadium catalyst was developed, e.g. platinum, glass, porcelain. A less pure form of sulphuric acid can be made by the Chamber process, in which sulphur dioxide is mixed with a nitrogen oxide and steam, and cooled in lead chambers. Several salts produced by sulphuric acid are used as fertilisers for crops—e.g. ammonium sulphate, calcium superphosphate.



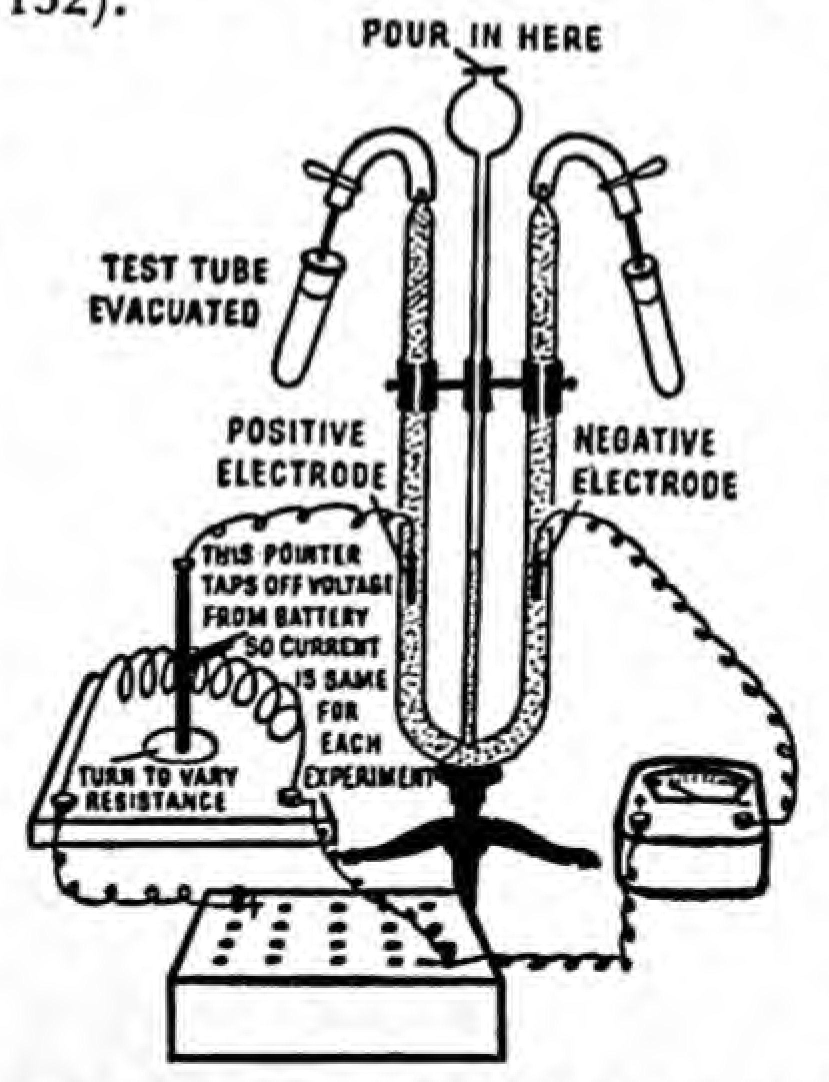
INTRODUCTIONS ARRANGED —THE WORK OF CATALYSTS

There are some reactions that at ordinary temperatures only take place slowly, yet by the addition of another chemical as a sort of "Master of Ceremonies" the two "shy" chemicals get together in a big way and react strongly. The "M.C." is called a CATALYST, it is not used up in any way, and can be recovered from the residue in exactly the same quantity and state that it went in. The popular laboratory example of this is to warm Potassium Chlorate until it melts at 368°C., when it gives off a very little oxygen. Now drop in the catalyst, Manganese Dioxide—and watch you don't get an explosion! The Oxygen pours out of the molten Potassium Chlorate.

Nobody knows for certain why a catalyst should have this effect. Different catalysts are necessary to bring about reactions between different pairs of chemical substances, and they have made industrial chemistry a good deal easier by allowing certain reactions to take place at lower temperatures. Water is the most widely effective catalyst (see Ionisation). Amongst the industrial catalysts finely divided metal powders (e.g. platinum) are the most commonly used. The enzymes of living tissues are also catalysts to reactions that sustain life—e.g. digestion, respiration.

Electrical Chemistry

Electricity does not at first seem to have much connection with chemistry but you get some unexpected results if you pass a direct current through solutions of some of the substances used in the previous experiments. The ammeter is in the circuit to check the amount of electric current being used. It works on a similar principle to the galvanometer (p. 190) and the variable resistance enables the current to be kept level. If this is done then the amount of electricity going through the circuit is exactly in proportion to the length of time for which it passes, and we know that if we let this "Electrolysis" go on for 3 hours three times as much electricity will have been used as for 1 hour. By the way nothing at all will happen if alternating current electricity is used (the reason is in the section on Accumulators, p. 132).



1. *Mixture of ·365 grams of Hydrochloric Acid and any amount of water.*

Report: Bubbles appear on both electrodes and solution is pushed down from the top of the tube on each side by the accumulating gases. If the current is maintained at 1 amp for just about 16 minutes and then switched off, the gas above the negative electrode will weigh ·355 grams and above the positive electrode there will be collected ·01 gram. of a different gas. On test these gases prove to be ·01 gram. of HYDROGEN, ·355 grams. of CHLORINE. The liquid left is water. The proportions of hydrogen to chlorine are 1 : 35½ by weight.

Note: When you switch off there *won't* be equal volumes of gas at each electrode. Chlorine is soluble in water, so the liquid has to be boiled to get off the chlorine, then its volume *does* check as 112 c.c. (see p. 127 for weight of 1,000 c.c. of a gas).

2. *Mixture of 1 gram. Sulphuric Acid* and enough water to fill the U tube.*

Report: Bubbles appear on both electrodes, and a gas collects above each. For 32 minutes of the same 1 amp electric current: ·02 gram. (222 c.c. in volume) of HYDROGEN collect above Negative Electrode, and ·16 gram. (111 c.c. in volume) of OXYGEN above the Positive Electrode.

The liquid left is still a weak mixture of Sulphuric Acid and Water. Two *volumes* of hydrogen have been obtained for every one of oxygen, but the two volumes of hydrogen only weigh ⅛th as much as 1 of oxygen.

* The Sulphuric Acid is added to make the water conduct electricity.

I

FARADAY'S LAW

Equal quantities of electricity discharge EQUIVALENT quantities of the ions of various elements or compounds.

96,500 coulombs of electricity (a coulomb is a current of 1 ampere flowing for 1 second) are needed to set free 1·008 grams. of hydrogen or one equivalent weight of any of the other elements.

3. *Solution of 1·57 grams. of Table Salt (Sodium Chloride) in enough Water to dissolve it.*

Report: Whilst the current is passing there is bubbling at both electrodes. If current flows for a double period (again 32 minutes) the weights of the gases given off are:

Above positive electrode: ·02 gram. of Hydrogen (222 c.c. volume).

At negative electrode: ·71 gram. of Chlorine (222 c.c. volume when boiled off).

The liquid if it is cooled crystallises and gives ·8 gram. of Sodium Hydroxide (Caustic Soda).

The equation for this experiment is:
$2\ NaCl + 2\ H_2O + \text{electrical energy} \rightarrow \uparrow H_2 + \uparrow Cl_2 + 2\ NaOH$.

Certainly electrolysis (that is what this process is called) has a great deal to do with chemistry! These quantities that have appeared at the electrodes are exactly the same as the "packages" of each substance that kept appearing in the earlier experiments, though sometimes one element appears as a double packet as you might expect from a knowledge of valencies.

A fixed amount of electricity is needed to set free a certain volume of hydrogen, and the same amount sets free the same volume of Chlorine (as in experiment 1). Avogadro had an explanation for this (page 127). In effect he suggested that equal volumes of two gases at the same temperature and pressure contained the same number of atoms, although the weights of these two volumes of gases differed. These results rather confirm that both Hydrogen and Chlorine have the same valency (i.e. one packet can join with one packet). One packet of Oxygen obviously must be combined with two of Hydrogen in the compound water so the valency of Oxygen must be 2.

Furthermore, both the Hydrogen and the Oxygen in experiment two must have come from the water—there certainly wasn't enough of either of these elements in the small amount of sulphuric acid added to make the water a conductor.

Ionization

Why should Hydrogen go to the Negative electrode and not to the Positive electrode?

The theory which explains these events makes use of the idea of IONIZATION. It says that when two substances react together in joining to make a compound one of them loses an electron (see p. 199) to the other. And because electrons are the negative part of an atom's electrical balance, the substance that gains the electron carries a negative charge, while the atom that loses an electron—not having enough electrons left to balance the positive charge of its protons is left carrying a positive charge. The compound itself is neutral of course because it contains the total number of electrons and protons to balance. But when electrically charged plates are put into a solution of the compound (like Hydrochloric Acid in exp. 1) the Chlorine atom carrying an extra electron is attracted by the pull of the positive electrode (i.e. attraction of opposites, see Magnetism), the Hydrogen atom (charged positive without its electron) moves to the negative electrode.

The different elements always keep their individual habits of ionization. Hydrogen always loses one electron. Its ION, as it is called when in this state, is shown as H^+. Oxygen always gains *two* electrons and its ION is shown as $O^{=}$. Aluminium always loses *three* electrons so its ION is shown Al^{+++}. There is a list on p. 128 of the ionization charges of some of the elements, Radicals (groups of atoms able to behave as a simple Ion) also have charges. This transfer of electrons, if you look at it with the Valency table, is the explanation of the "joining habits" of atoms. See also pages 193–199.

Ionization in Watery Solutions

Although *pure* water is practically a non-conductor of electricity, the addition of any of the acids, bases or salts makes the solution conduct. Yet these substances when quite dry are mostly non-conductors. Ionization is explained as a process whereby as an increasing proportion of water is added to an ELECTROLYTE the IONS of the elements, or radicals of which they are composed, become separated (=dissociated). That is, if water is added to Table Salt (Sodium Chloride), which is existing as molecules each of two paired IONS: Na^+ and Cl^-, then the two kinds of ion separate from one another and move in the solution quite independently. The very fact that the salt is dissolved helps to separate the Ions; the weaker the solution is made the greater number of molecules split into separate Ions, so with enough water on a tiny amount of salt every molecule will have split. There will be a great number of + ve Sodium Ions and an equal number of — ve Chlorine Ions. If two fresh substances which can more readily form new compounds with the free Ions are placed in the solution, the Ions will migrate towards them. Alternatively, if charged electrodes are introduced into the solution the ions will move towards the electrode carrying the charge opposite to their own.

Chemically Made Electricity

If an electric current can cause the two ions that make a compound to journey towards the opposite electrodes, you would think that metals put into acids or other substances that react with them might cause enough ions to get separated to create an electrical charge. And this is so. The storage battery works like this when it is first set up.

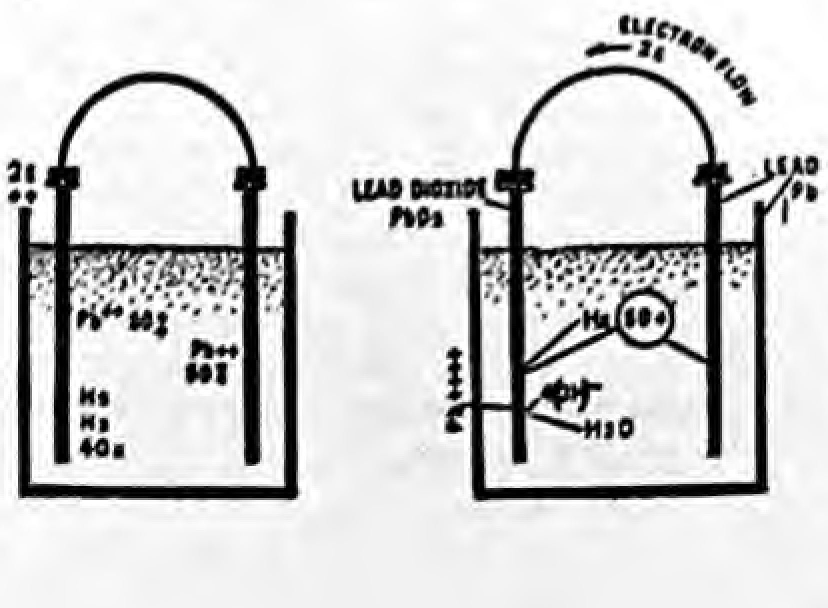
The electrolyte is a dilute solution of Sulphuric Acid.

One plate (the "anode" or + ve one) is made of Lead Dioxide, PbO_2, and the other (the "cathode" or − ve one) is the element Lead Pb. The valency of the Lead in Lead Dioxide is four (Pb^{++++}), as you can work out, for the valency of Oxygen is two and the formula gives Lead Dioxide as: PbO_2, (i.e. the Pb must be balancing $O^{=}$ $O^{=}$). But the valency of lead combining with the $(SO_4)^{=}$ ion of Sulphuric Acid (H_2S_4O) is only two (Pb^{++}).

It is out of the difference of charges on the two kinds of Lead ions that electricity is produced in the accumulator.

Water is present with the Sulphuric Acid to dilute it, and as the reaction begins a *reversible* reaction (sign $\rightleftharpoons$) happens that produces four $(OH)^-$ ions:

$$PbO_2 + 2\,H_2O \rightleftharpoons Pb^{++++} + 4OH^-.$$



The Pb^{++++} lead has two more ++charges than it needs in joining with the $(SO_4)^{=}$ radical of Sulphuric Acid. If a wire connects the + ve and − ve plates so a current can flow, these two spare charges produce a pull sufficient to bring over two electrons from the other plate to balance them. This is written

$$Pb^{++++} + 2e = Pb^{++}.$$

The electrons from the − ve plate (the lead one) are obtained from the lead as it loses its normal electrical balance to form its ion Pb^{++}. This is written

$$Pb = Pb^{++} + 2e.$$

And on the negative (lead) plate this leaves a lead ion Pb^{++} and a $(SO_4)^{=}$ radical in the right state to combine as Lead Sulphate:

$$Pb^{++} + SO_4^{=} = PbSO_4.$$

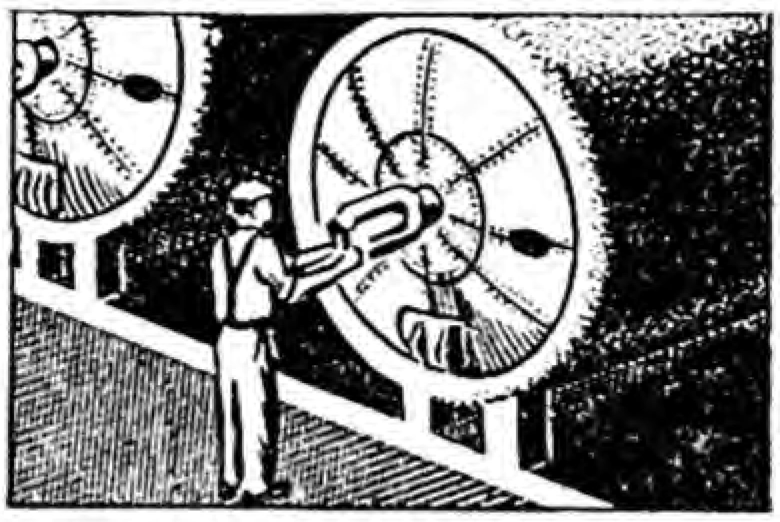
Exactly the same state has been reached on the positive (Lead Oxide) plate—Pb^{++} is ready to join with $(SO_4)^{=}$:

$$Pb^{++} + SO_4^{=} = PbSO_4.$$

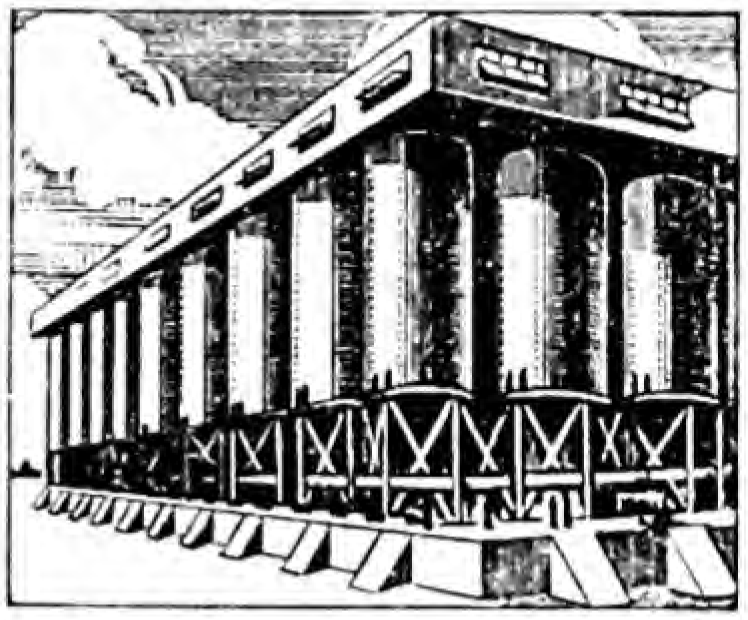
But that does leave us with those $4(OH)^-$; surely they need balancing? Yes, but for clarity we didn't write the whole equation of the forming of lead sulphate. *Both* the above equations should have been:

Aluminium

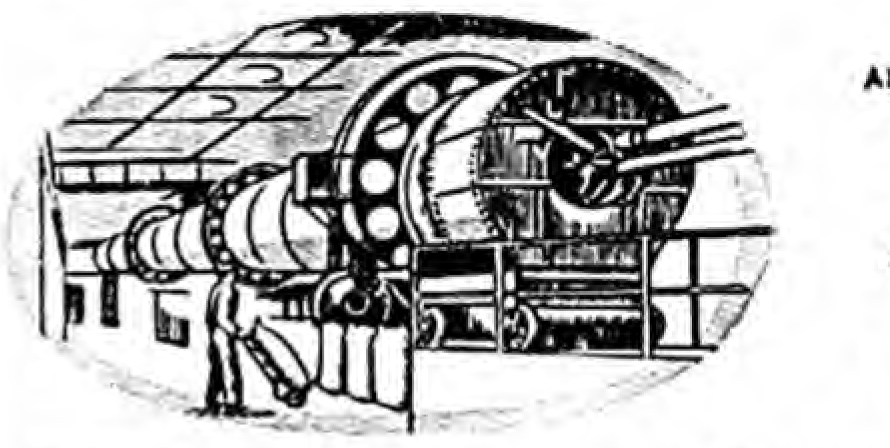
Aluminium is the earth's most abundant metal, although not all the ores which contain aluminium have sufficient of it in a pure enough form to make it worth extracting. Bauxite is a rock rich in aluminium. The name Bauxite is from the district in France where the aluminium-bearing rock was first discovered.

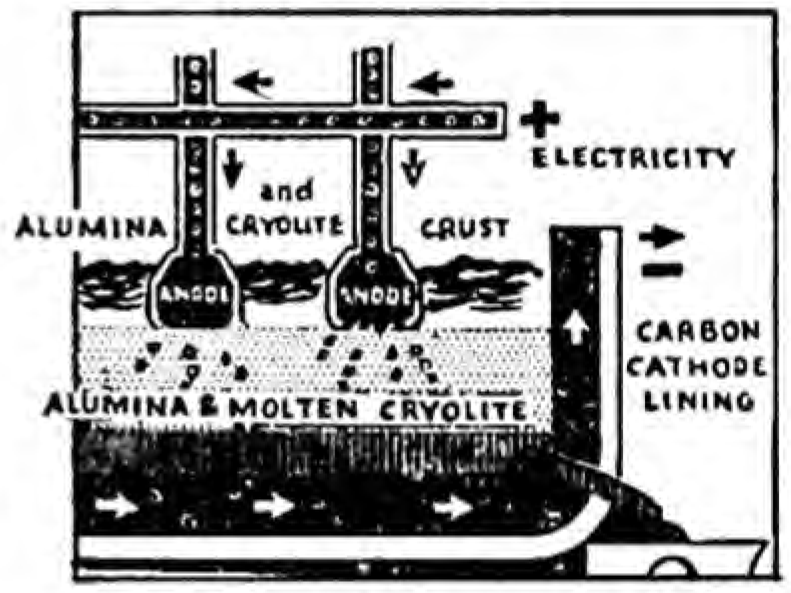


After washing and crushing, the bauxite ($Al_2O_3 2H_2O$—hydrated aluminium oxide), ground to powder, is mixed in pressure tanks with hot caustic-soda solution and pumped into pressure tanks called digesters or autoclaves. In this process, the solution is kept at high temperature and constantly agitated (stirred) to dissolve all the aluminium oxide in the bauxite. Soluble sodium aluminate is formed ($Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$). The compounds of iron, silicon and titanium and other impurities, which are insoluble, are removed by filtering.



Precipitation. The sodium aluminate solution is pumped into tall precipitation tanks and the saturated solution, to which is added a "seed" of aluminium hydroxide crystals, is slowly cooled. Crystals of aluminium hydroxide, $Al(OH)_3$, form in the mother liquid.





Calcination. The crystals of the hydroxide are heated in long, inclined revolving drums (*left*) to drive off the water of crystallisation, and aluminium oxide, Al_2O_3 (alumina), a white powder, is left. The alumina is placed in a bath of molten cryolite (the electrolyte) in which it dissolves. Cryolite is itself an aluminium compound with fluorine and sodium, $3NaF, AlF_3$, and is used because aluminium oxide has a high melting point, though it will dissolve in cryolite. The furnace is lined with carbon which is the cathode. When the anode rods of carbon are lowered to make contact with the surface of the cryolite, current passes through it to the carbon lining and is conducted away to complete the circuit. The passage of electricity creates great heat, maintaining the temperature of the bath at about 1,000°C. Pure aluminium is slowly deposited electrolytically on the bottom of the cell and is periodically drawn off. The oxygen which is liberated rises to come into contact with the red-hot carbon anodes and forms carbon monoxide. This burns on the surface to form carbon dioxide, which is led away by flues.

$Pb + H_2SO_4 \rightarrow PbSO_4 + H_2$

$Pb + H_2SO_4 \rightarrow PbSO_4 + H_2$

—shouldn't they?

Add up the Hydrogen $\overline{4H}$

Each Hydrogen ion has one + ve charge, so this is $4H^+$ (four positive ions).

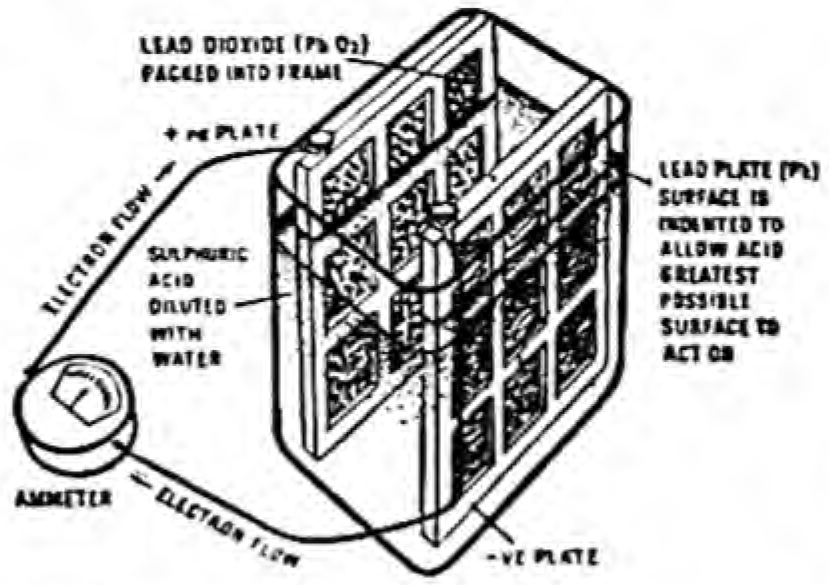
They will join with the $4OH^-$ (four negatives) radicals to form water:

$4OH^- + 4H^+ = 4H_2O$

As long as the two plates are connected by a conductor the + ve plate will keep on pulling over electrons to balance the extra positive charges the Pb^{++++} puts on it. If the conductor is disconnected the electrons won't be able to get round and balance things up, so the Pb^{++++} won't be able to become Pb^{++} and form Lead Sulphate. The reaction stops.

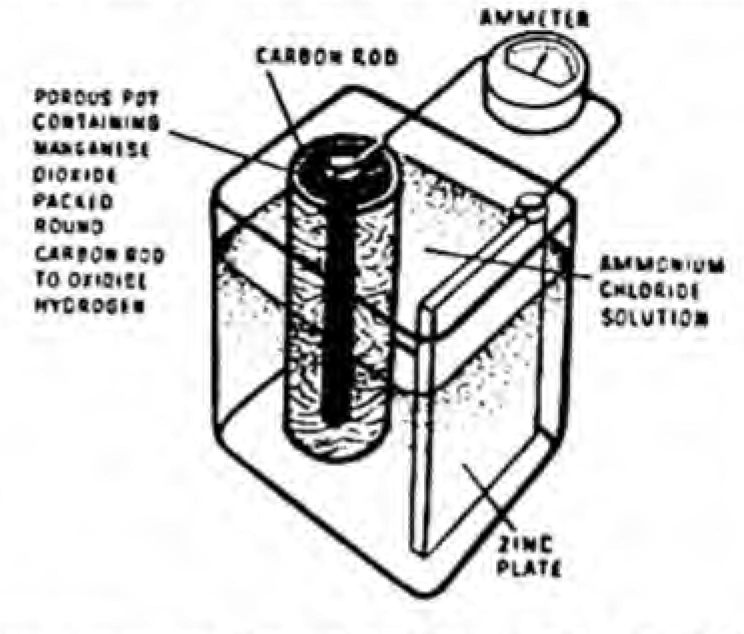
But while the electrons can get round the reaction goes on until all the lead on both sides has been covered with lead sulphate. Once it has the Sulphuric Acid cannot get at it and the reaction stops, and so does the electric current flow—the accumulator is "flat".

But there is no need to throw it away; a *high-voltage* current of Direct Current electricity passed through it in the REVERSE DIRECTION will reverse the whole process and the lead sulphate will disappear from the plates and they will become lead dioxide and lead as they were when new. For the + ve plate now being negative, and the negative + ve, the Hydrogen H^+ ions and the $(SO_4)^=$ ions and $(OH)^-$ ions will travel in the usual way of electrolysis to their oppositely charged plates, and so change the balance back to what it was before. When that is done the accumulator is ready to start delivering electricity all over again. This charge-discharge cycle can be repeated provided the sulphuric acid and water are replenished if they evaporate, until wear and tear destroys the structure of the cells.



Batteries

Batteries differ from accumulators (or storage batteries as they are sometimes called) in not being rechargeable since the electrolytic reactions by which they make electricity are not reversible as with lead and sulphuric acid and water. So they have to be thrown away when their plates are covered with the finally balanced compound—when they are "flat".

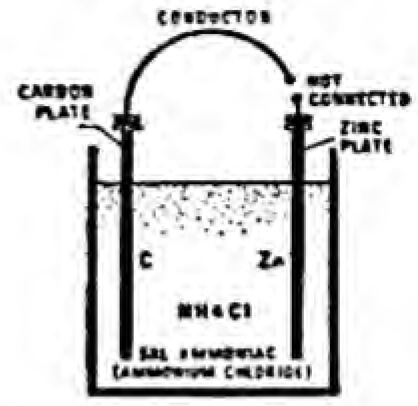


The Simple Leclanché Cell. Zinc from the zinc plate dissolves in the Ammonium Chloride (Sal Ammoniac) solution, and Zn^{++} ions travel away from the zinc plate into the solution to join with the Cl^- chlorine ions to form a solution of Zinc Chloride ($ZnCl_2$) so leaving the Zinc plate with spare electrons. These flow round the conductor to the carbon plate. For the radical $(NH_4)^+$ has been released from the ammonium chloride and its + ve charge needs balancing. We say the $(NH_4)^+$ is attracted by the negatively charged carbon plate. When it reaches the carbon plate the NH_4 ion breaks down into ammonia and hydrogen (both with balanced charges).

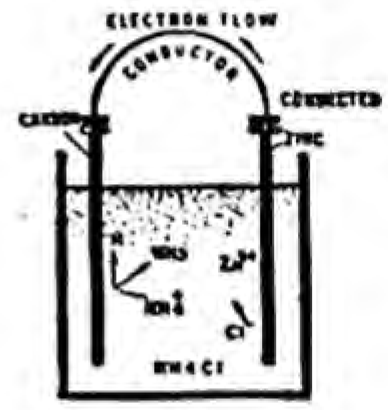
Dry Cell

$$2(NH_4) \rightarrow 2NH_3 + H_2$$

The ammonia stays in solution but the bubbles of hydrogen would blanket the carbon plate and stop the reaction (this is called "polarisation") if they were not disposed of. This is done by packing manganese dioxide round the carbon plate,



the hydrogen will slowly combine with this to form hydrogen monoxide (water H_2O). When all the sal ammoniac solution has been used up the cell is "flat", and no more use. If the cell is too quickly discharged (i.e. the electron flow made too



easy in the conductor) the manganese dioxide may not be able to cope with all the Hydrogen formed and the current may temporarily cease to flow until the reaction catches up and the carbon plate is again uncovered.

The ordinary dry cell used in dry batteries is an ingenious adaptation of the Leclanché cell.

Positive and Negative

It would not be fair to say that the early experimenters developing batteries and other electric equipment made a mistake in defining which plate was the Positive one, and which was the Negative one. They quite reasonably based their arbitrary definition on electrostatic considerations which seemed more important then than they do now. But every student today curses the old definition though everyone has to use it because the whole electrical world has always used it—because it is in fact electrons which provide the current. Since the electrons are negatively charged they move along the conducting wire towards the positive terminal of the cell. This is in the opposite direction to that in which the "current" is said to flow! (Positive towards negative). In the Leclanché cell the electrons go from the zinc plate through the conductor to the carbon rod, yet the carbon rod is *called* the + ve plate, and "electric" current is said to flow from the + ve carbon plate, through the conducting circuit, to the −ve zinc plate. Very puzzling! But it won't confuse you as long as you always think out which way the electrons flow.

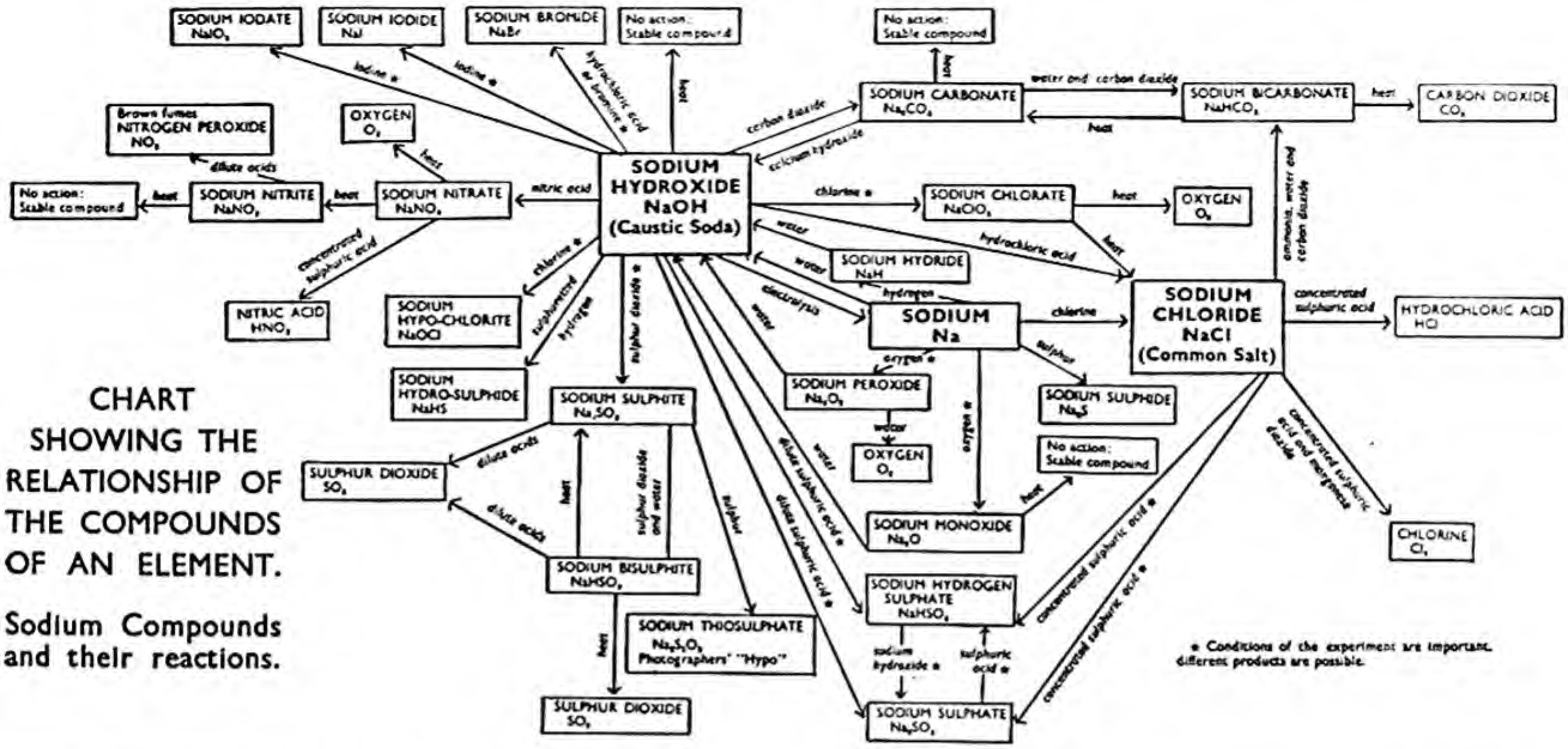
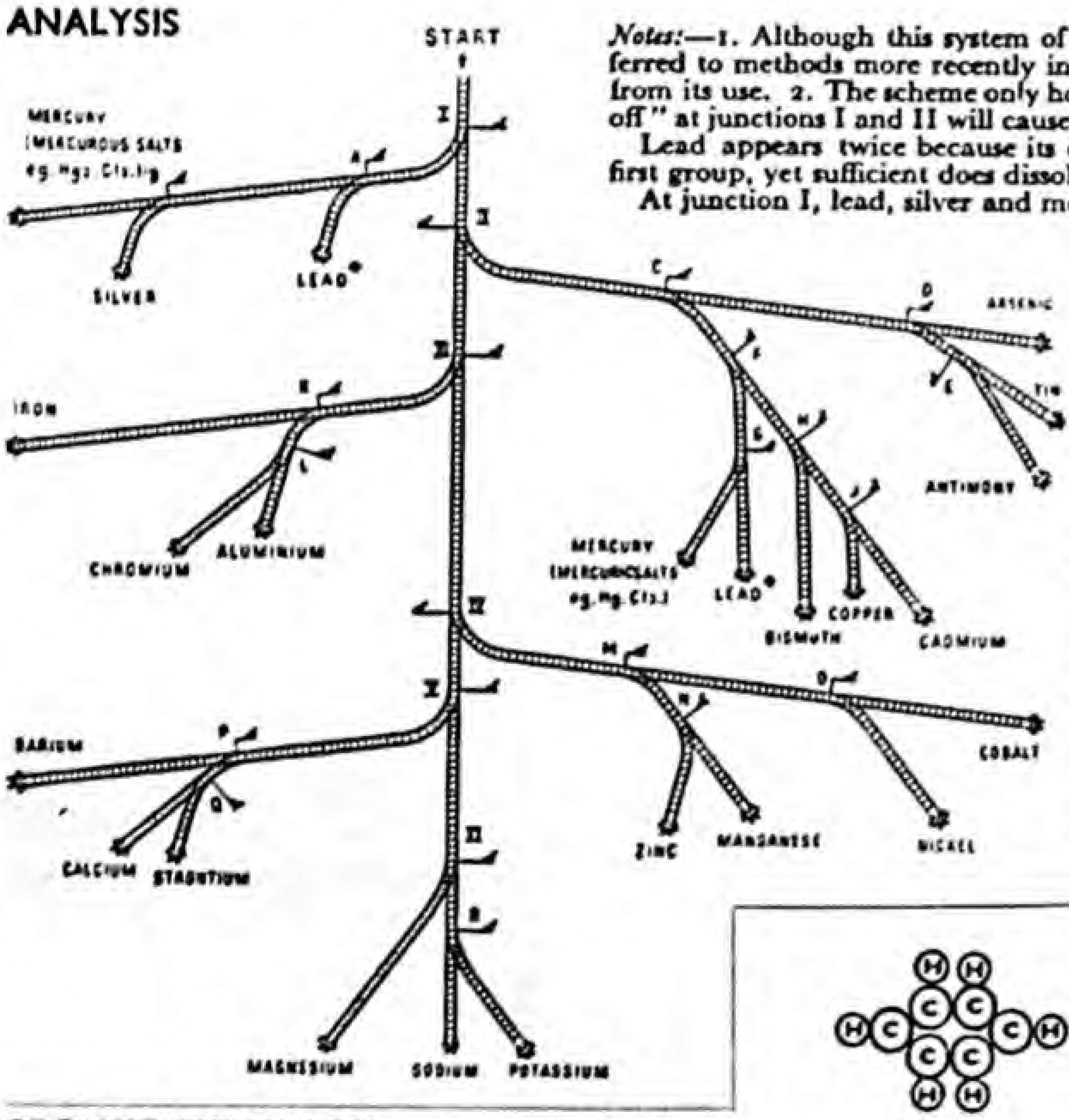


CHART SHOWING THE RELATIONSHIP OF THE COMPOUNDS OF AN ELEMENT.

Sodium Compounds and their reactions.

ANALYSIS



Notes:—1. Although this system of analysis is a little cumbersome and is unpleasantly smelly in places, it is generally preferred to methods more recently introduced, largely because there is a great deal of very important chemistry to be learned from its use. 2. The scheme only holds good if a start is made at the beginning. e.g. Metals which should have been "shunted off" at junctions I and II will cause wrong results if present for later tests.

Lead appears twice because its chloride is *fairly* insoluble in water. Enough remains undissolved to bring lead into the first group, yet sufficient does dissolve to get past junction I and so affect group II.

At junction I, lead, silver and mercurous salts are "shunted off" because their chlorides are insoluble in cold water. At A, lead is diverted because its chloride dissolves in hot water. At B, silver is "shunted off" because its chloride dissolves in ammonium hydroxide solution.

At junction II, mercuric, lead bismuth, copper, cadmium, arsenic tin, and antimony salts are shunted off because their sulphides are insoluble in dilute hydrochloric acid. At C, arsenic, tin and antimony pass on because their sulphides dissolve in boiling sodium hydroxide solution, the remaining five metals being diverted. At D, arsenic passes on because its sulphide dissolves in ammonium carbonate solution, tin and antimony being diverted. Tin passes straight across E because it forms insoluble tin hydroxide with potassium hydroxide and ammonium chloride solution; antimony, which stays in solution being "side-tracked".

At F, lead and mercury are "shunted off" because they form insoluble substances when their sulphides are warmed with dilute sulphuric and nitric acid mixed. At G, lead passes through, because the insoluble lead compound re-dissolves in boiling ammonium acetate solution: the mercury compound, being still insoluble, is "side-tracked".

At H, bismuth is "shunted off" because it forms an insoluble compound when ammonia is added to the solution containing bismuth, copper and cadmium, the other two metals remaining in solution. At J, copper is diverted because of the deep blue colour its salts form with ammonia solution.

At junction III, iron, aluminium and chromium compounds are side-tracked because they form insoluble hydroxides with ammonium chloride solution and ammonia. At K, aluminium and chromium are diverted because their hydroxides dissolve when heated with water and sodium peroxide. At L, chromium is "side-tracked" because of the yellow colour of the solution.

At junction IV, zinc, manganese, nickel and cobalt are diverted because they form insoluble sulphides with ammonia solution and sulphuretted hydrogen. At M, zinc and manganese are "side-tracked" because their sulphides dissolve in cold, very dilute hydrochloric acid. At N, manganese is allowed through since it forms a brown precipitate when sodium hydroxide is added to the solution containing manganese and zinc.

The nickel and cobalt sulphides are dissolved in hot concentrated hydrochloric acid and diluted. At O, nickel is diverted when it is recognised by a bright red colour with a complex organic reagent, di-methyl glyoxine.

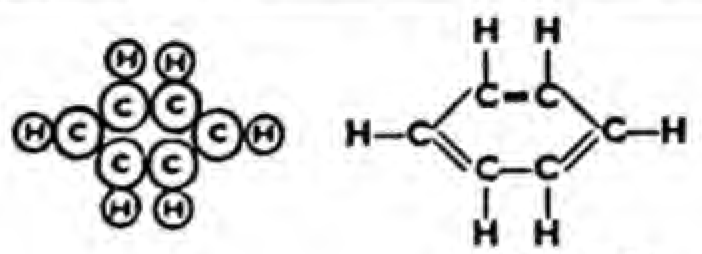
At junction V, calcium, strontium and barium are "shunted off" because they form insoluble carbonates on boiling with solid ammonium carbonate. Barium is allowed straight through at P because its soluble compounds form a yellow precipitate with potassium chromate solution, calcium and strontium going on to the side-track. At Q, strontium is diverted because it gives a white precipitate of strontium sulphate on boiling with calcium sulphate solution.

At junction VI, magnesium is "side-tracked" when it gives a crystalline precipitate with ammonia and sodium phosphate solution. At R, sodium is recognised and allowed straight through by its ability to turn a bunsen flame bright yellow. Potassium may be shunted-off because of its ability to form a precipitate after standing with tartaric acid.

The exact details of such an analysis, and many confirmatory tests can be found in any text book on systematic qualitative inorganic analysis.

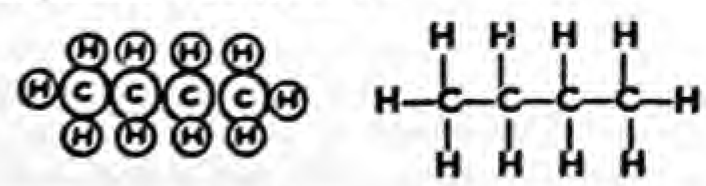
ORGANIC CHEMISTRY

Today Organic Chemistry means simply the part of chemistry which is concerned with the compounds of the element Carbon. Already over 500,000 carbon compounds are known, most of them artificially manufactured and not occurring in nature. They are among the most useful of the chemist's discoveries. Naturally occurring ones include the *hydrocarbons* (petrol and other fuel oils, and many inflammable gases, like Acetylene); the *carbohydrates* (the sugars and starches, which, broken down by catalysts called enzymes, build and supply energy to the body cells of living tissues); *alcohols* (industrial spirit), and *ketones* (acetone, the solvent of varnish and celluloid); *organic acids* (many processes of digestion and fermentation produce acids of this sort—one of the compounds of organic acids with an alcohol is glycerine, the basis of fats). Its power to combine into elaborate and large molecules is the reason why carbon is the most important element industrially and biologically. Some organic compound molecules have their atoms linked in chains, some in rings; an example of the latter is benzene:



═ is double bond, i.e. spare valency.

The early chemists thought these carbon compounds, because they were then prepared from things that had been living tissue (wood, coal, horns, urine), contained a "vital force", so they were called "organic", to distinguish them from inorganic ("lifeless") compounds prepared from rocks or other "dead" substances. Eventually the organic compounds were prepared from the inorganic chemicals, and the name organic chemistry was only retained because of the special ability of carbon to form such a vast number of compounds.



C_4H_{10} Butane

WHAT IS SCIENCE?

If you look up the word science in the dictionary you will find that it means knowledge, knowledge of anything. In this sense theology is sometimes spoken of as the queen of sciences. But in this book we use the word science as meaning natural science. This is the investigation, by a process of trial and error, of the natural world—that is to say, the world we can observe and measure. Natural science in this sense grows both out of curiosity and out of necessity. It has probably a history as long as man himself, though only in the last 200 years has it come into its present very effective form.

Science is only possible when a man is allowed by his fellows to call in question what is generally accepted as true, and is himself able to give up old beliefs when they no longer prove to be in agreement with facts that have newly come to light. That is to say a scientist must be open-minded, though this is by no means the same thing as being empty-headed!

Science as a Method

Science starts from *observation*, observation that is made both as accurately and as abundantly as may be possible. Only in this way can the situation being studied be clearly discerned and its uncertainties recognised.

After making suitable observations the next stage is to develop some explanation of what has been seen to happen. A possible explanation is called an *hypothesis*, and normally there are several alternative hypotheses that would seem able to fit the facts. These must all be brought to light by a process of the mind known as *induction*, which is in a sense no more than a process of guessing, an exercise of the imagination.

In everyday life, too often people are satisfied with their guesses just because they are their own guesses! In science it is necessary to guess as many alternative explanations as may seem able to explain the facts, and then to sort them out for their usefulness by means of their success in foretelling situations not yet investigated. To do this another process of the mind, using the department of logic known as *deduction*, is brought into operation. Each hypothesis is examined in turn to see what must be implied by it if it is true, what should follow if it is correct. This is, if you like, making the hypothesis prophesy.

Next comes the crucial stage in scientific method: *verification*, or the testing of the various prophecies by appeal to more observation. This involves a manual process, an operation of the hands, and use of the senses. Whenever possible the testing observations are made in the form of what is called an experiment. In this case observations necessary to test the reliability of the hypothesis in prediction are made in conditions that are under the control of the research worker. If the hypothesis on test fails to predict what actually happens in the experiment it is regarded as useless and is discarded. If it does predict correctly, it is not held to be true beyond doubt, but merely to be true *as far as it goes*.

Where a hypothesis cannot be tested under the stricter conditions of an experiment it may have to await the making of observations as and when these become possible in the course of nature. In astronomy it is not possible to compel the heavenly bodies to move into any particular conjunction necessary for the testing of an hypothesis, but, as and when that does happen, it is possible to test theories and hypotheses that have been advanced previously.

In the course of the continued making of further observations, whether in experiments or otherwise, facts come to light that at last show the weakness of the hypothesis previously accepted as true. Then the making of a better hypothesis becomes necessary and our method goes round its course again, as it were in a circle—but not truly in a circle, rather in a spiral, because this new cycle of development is at a higher level of understanding.

This introduces us to the idea that the scientist's "truth" is relative; it is an approximation; and old "truths", in this sense, will be given up when newer and better ones can be invented in their place. This explains what is for some people one of the greatest stumbling blocks about science: that it is not final in its conclusions! Scientists are always prepared, indeed delighted, to change to new explanations if these lie closer to the known facts.

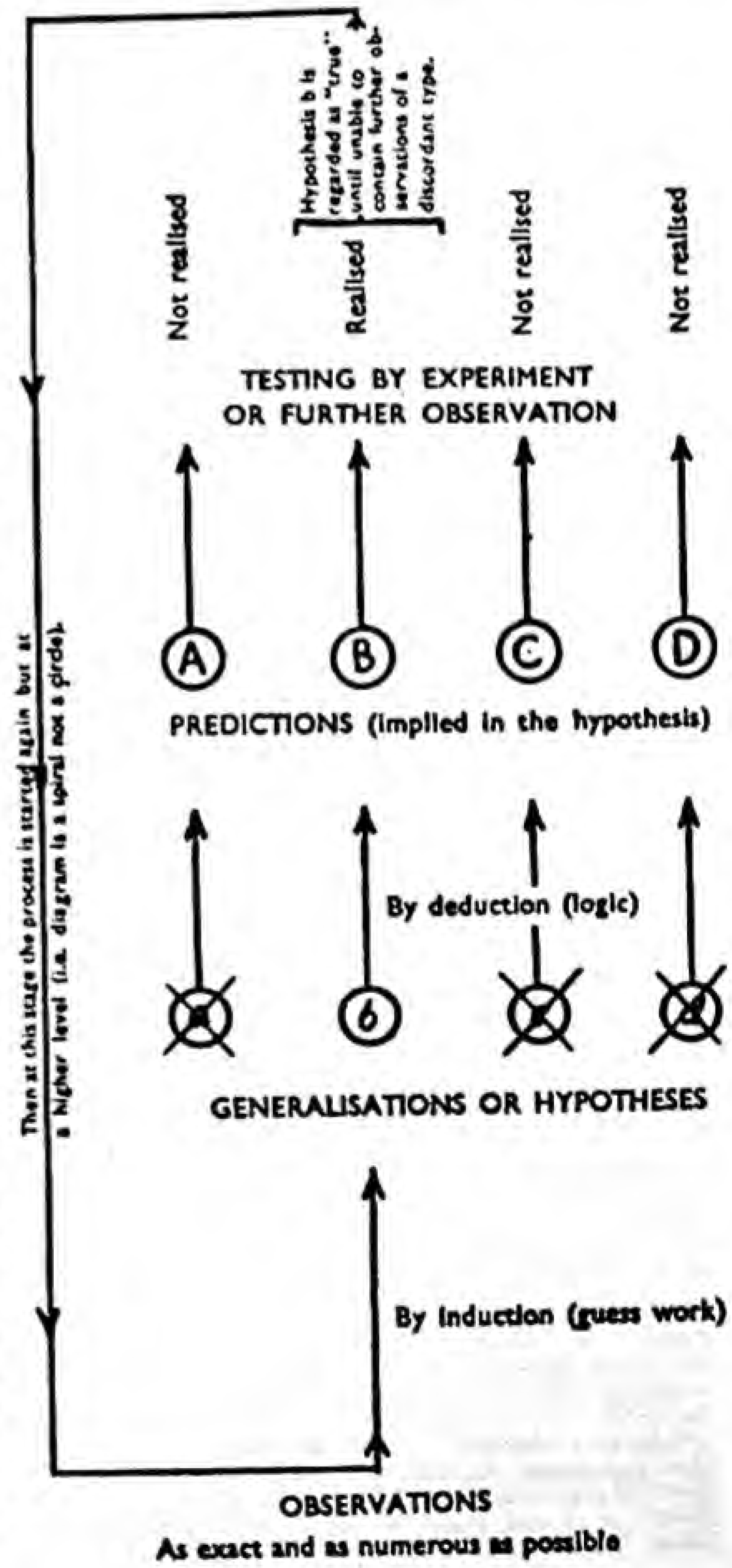
Scientific truth, then, is not final. It represents the stages reached at any one time in the quest for understanding. The level of success in this quest is always to be measured by the degree of agreement between statement and fact. Scientific truth represents the best that can be done at any moment. It has no authority to prejudice further enquiry in the field to which it applies.

Acceptance of any scientific hypothesis as being true does not result from any quality of elegance nor from the sincerity or the enthusiasm with which it is advanced; neither does it rest on any other personal grounds, such as, that it is your own hypothesis, or the hypothesis of someone you greatly respect. The only grounds for accepting any hypothesis as being true for the purpose for which it is invented is that it works—that it does in fact serve the purpose of holding together a large number of existing facts, and predicting facts as yet unknown. This is very unlike the idea of truth as understood in other walks of life, and it is one of the distinguishing features of the scientific attitude.

What is a Scientific Experiment?

An experiment is a situation so arranged that the material that is being observed provides by its very behaviour its own answer to the question that is being posed. If it does this, then it declares an answer Yes to the question; if it does that, it declares an answer No—and so the solution of the problem is made impersonal and independent of the whim or the fancy of the person who is conducting the experiment. An account of the design, course and result of the experiment is in time published, so that anyone else may repeat it for the purpose of checking the experimenter's conclusions.

In any experiment it is necessary for only one of the conditions of the experiment to vary at a time. Otherwise what is seen to happen cannot be linked up definitely



with one changing factor that may then be thought of as responsible for it. If you were servicing a car engine that refused to go, you wouldn't in one operation replace the plugs, clean the carburettor, reset the points, etc. You would recondition one of these things at a time, until at last you came to whatever it was you had to do to restore the engine so that it would restart. You could then say that the engine failed to work *because* of whatever it was that you had discovered to be at fault.

In experiments where, because of insufficient knowledge, it is not certain that only one factor is being altered at a time, it is necessary to set up a parallel experiment, called the control. For example, if you have to put a plant in a glass vessel to discover what happens in its leaves when the surrounding gases are changed, you must also set up another plant in a glass vessel without altering the gases around it. This will show whether or not anything that happens in the other part of the experiment is merely the result of the plant having, of necessity, been shut up inside a glass vessel.

Science and Man

So much for the way in which scientific knowledge is advanced. Now a little about what science can do for man, and what it cannot do.

It extends the range of his senses enormously, as you will see by reference to those pages of this book which deal with some of the remarkable scientific instruments now available. It also increases man's foresight (the ability to foretell what can be expected to happen in advance of it actually happening). This is of great assistance to man both in enabling him to by-pass difficulties that he might otherwise have to endure, and in giving him the power to secure results that he has planned for in advance. In this way science enormously increases the means at man's command for the achievement of his aims, whether these be constructive or destructive. It is the source of power in action.

Science cannot, however, deal with the unobservable. It can deal with electrons, not themselves directly observable, because these are observable through the measurable tracks that they leave behind, as shown in the article on physical particles (*see pages* 193–9). But though science can deal with electrons it cannot deal with propositions about angels, even should it in fact be the case that guardian angels govern our individual behaviour. Angels, by definition, not being part of the natural world, the impossibility of treating such propositions by scientific method is apparent.

Equally, science does not replace wisdom. It cannot judge between the alternative ends that we set up as our individual or collective ambitions, though it may give us the means by which the more readily to achieve those ends. At least for the present scientific method is unable to tell man what it is *best* to see, or what it is *best* to like. Some people think that it never will be able to do this, though scientific knowledge sometimes warns us in advance of the consequences of our choices.

Science is not the mere accumulation of encyclopaedic knowledge. It is not exactly common sense—at least as far as some of its conclusions are concerned—as you may have already concluded from reading the article on the physical nature of the world about us! It is, however, thoroughly "common sensical" in its reliance upon trial and error. It is not a body of doctrine resting upon the authority of persons. It is not the mere pursuit of gadgets, though gadgets in their variety have resulted from the advancement of scientific knowledge.

Science *is* a way of enquiring. It is a *method* of advancing knowledge about those happenings that can be seen and measured. It is an *adventure* into the unknown in the pursuit of understanding; understanding that is to be reached by the use of trial and error, operated wherever possible under the controlled conditions of an experiment.

The Several Departments of Natural Science

Physics (which is the study of the various properties of matter and of radiation) and chemistry (which is the study of the interactions of matter to produce new materials) are the fundamental sciences that deal with the inanimate world. Measurement, often with great accuracy, is possible in connection with observations in these subjects. The setting up of precise experiments is almost always possible.

But science consists of much more than physics and chemistry. Astronomy and geology are two sciences in which progress is chiefly made by convenient observation rather than by deliberate experiment. Science also includes biology. Biology is a group of subjects concerned with the world of living things. It is, in general, much less exact than physics and chemistry, and builds its theories as far as possible upon the findings of physics and chemistry. Though less exact than these sciences biology is equally a part of natural science. It divides into the botanical sciences having to do with plants, and the zoological sciences, having to do with animals. Both these departments of biology have sections dealing with anatomy (structure) and with physiology (function). Bio-chemistry and bio-physics deal with the chemical changes and physical changes that can be detected going on in the bodies of living plants and animals. They approach the exactness of chemistry and physics.

The study of the evolution (origin and ancestry) of living things quite obviously links up with the whole study of history, just as ecology (*see pages* 200, 201) (the study of the social relations of plants and animals) links up with the study of human sociology. Now history and sociology are not ordinarily thought of as related to natural science. The fact that natural science in these fields links up with other lines of human enquiry again raises the question whether scientific method has yet reached the limits of its possible application.

SCIENTISTS

In a sense we are wrong in talking of science as if it existed by itself. Science is only the name for a human activity. Science is only the work and findings of scientists. It is not a sausage machine grinding out relentless results. The success of the method must depend on the integrity and the competence of those who use the method; i.e. on the qualities of individual scientists. Scientists are not normally men who wear an outsize in hats, though the current description of them as backroom boys rather suggests this, and might also imply that they are not altogether presentable! Scientists are men like others, but they happen to be men with special interests and abilities, just as other men in other walks of life have their special interests and abilities. Scientists are not merely intellectual workers. They have to be skilled with their hands in setting up experiments, and in devising tools or instruments with which to advance the accuracy of their observations. They are, therefore, men of two worlds, having both manual and intellectual skills.

Now that by reading the various parts of this book you have learnt something of what scientists do, and concerning the adventure of their work, you may be interested in science as a career for yourself. To help you in this connection, we have included this little box entitled *How to Become a Scientist*.

HOW TO BECOME A SCIENTIST

A. Right Temperament.

There isn't probably much that you can do about this. To have the right temperament is, however, most necessary. 1. There must first be a desire to know. 2. There must also be patience to find out and to compare. 3. There must be a willingness to discard ideas that will not fit the facts (i.e. there must be freedom from prejudice), though sometimes genius may be in holding to a "hunch" even in the face of what for a while seems to be contrary evidence.

B. Necessary Skills.

All these can be increased by practise and by training. 1. It is necessary to have the ability to observe accurately. 2. Manual skills are needed to make and to use apparatus effectively. 3. Intellectual skills are necessary in order to draw sound conclusions from observations. This involves using, according to the circumstances, logic or mathematics. 4. It is necessary also to have imagination, with which to arrive at possible theories to explain the facts that you and others have collected. 5. Ingenuity in designing test situations in which these hypotheses can be made to undergo the test of verification is another necessary skill.

C. Professional Entry.

This is possible by several routes. 1. A university career arising from a grammar school preparation can lead to advanced training for scientific research, for technology or for scientific administration. 2. Entry into scientific industry directly from school as a scientific assistant or as an apprentice can provide specialised training, both at work and by way of further education at technical colleges.

D. Amateur Status.

Don't forget, however, that science is not just a profession. Many great advances in science have been made by men who did not earn their livelihood from scientific work. Scientific method can be practised at the wash tub, in the kitchen or in the garden, out of doors at weekends—indeed wherever you happen to be! And the use of it will greatly increase the interest of whatever you may be doing or seeing.

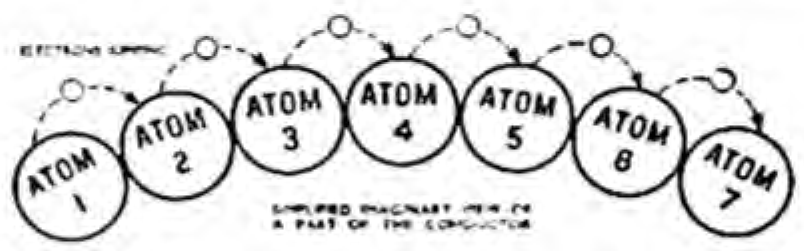
THE ELECTRICAL ENGINEER'S USE OF ELECTRICITY

The nature of electricity is studied by physicists in their examination of the properties of matter (*see pages* 193–9), for all electric currents are changes in the state of the atoms of the conducting material. But the electrical engineer is chiefly concerned with the design of electrical machines to do useful work.

He usually talks of the flow of electric current as if it were rather like water flowing through a pipe, though really it is somewhat different. Atoms consist of heavy particles at the centre called Protons, with lighter particles called Electrons flying round them like planets round a sun.

Some materials (mostly metals) conduct electricity easily—they are called Conductors. Some other materials practically do not conduct at all—they are called Insulators or Dielectrics.

If a piece of any material is imagined to consist simply of a row of atoms, then when an electric current is flowing through it a source of unbalance has caused the atom at one end of the conducting material (called Negative) to have more than the normal number of electrons, and the atom at the far end (called Positive) to have less than the normal number. The atoms try to get back to normal. In metals the outermost electrons are believed to move about in the spaces between the atoms. Normally they move in all directions, but when the electrical balance is upset they move towards the positive end (which is positive because it is short of electrons) until they can each jump into an atom which has an electron short. In some other materials it is considered that the extra electron is only able to jump out of the first atom into the next atom. This second atom now has

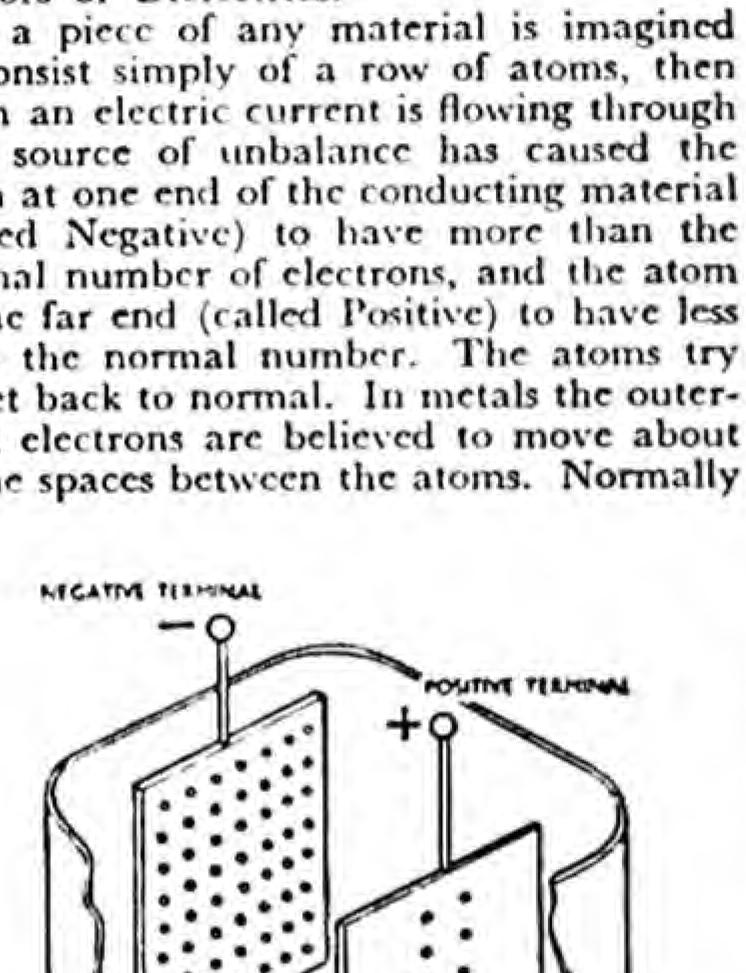


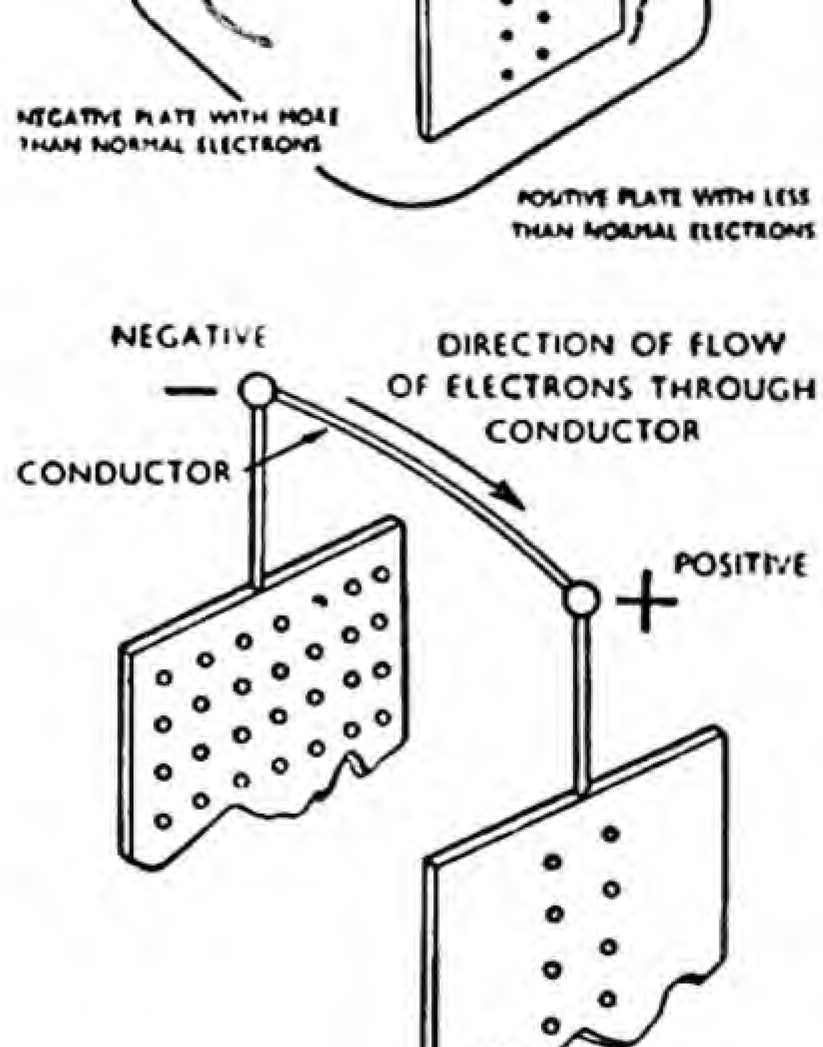
more than the normal amount of electrons, and in turn one of its electrons is pushed out and jumps into the next atom. And so on until an electron jumps into the atom at the positive end of the conducting material which is short of electrons, and makes the unbalance less by one electron. Of course in practice the source of unbalance (or Potential Difference, as it is called) causes thousands of millions of atoms to have, on the negative terminal, an extra electron each; on the positive terminal, each an electron short.

The best conductor of electricity is gold, but fortunately copper, which is a good deal more plentiful, is nearly as good, and practically all electric wiring is made from it. The greater the cross-section of the wire the greater the flow of current can be through it, for there will be more rows of atoms to transfer electrons from one side of the source of unbalance (potential difference) to the other. For this reason thicker wire is used to connect an electric fire than an electric light: the fire allows a greater current flow.

We have said some materials conduct more easily than others, and of course the more easily electrons move along a conductor the less energy is wasted in making them move. The electrical engineer thinks of a conductor as in some ways resembling a water pipe through which he is "pumping" water at a certain pressure. While the water flows through a fairly wide pipe it moves at a steady slowish rate. But suppose the pipe narrows. What happens to the water? The same volume of water must somehow get through the thinner pipe; if it doesn't there will be some water left over somewhere and there is no room for that. The water moves *faster* through the thin pipe, and slows down again when it gets to the wide pipe beyond. So the pressure of the water at the beginning of the narrow pipe will be high; at the end of the narrow pipe it will be low.

In an electrical circuit the "narrow pipe" is a Resistance—i.e. a piece of conductor made of a material (say carbon) that does not conduct an electric current so easily as the rest of the conductor ("the wide pipe"), i.e. copper wire. The electron pressure on the atoms at the entrance to the high resistance will be high, and because of this the number of electrons moving along it, in spite of its *resistance* (its tendency to hinder their flow), will be the same as in the good conductor.





Like the water pipe, the flow is the same in all parts of the circuit. This flow is called the Current. But at the end of the high resistance ("narrow pipe") the pressure will have become very small now that there is practically no resistance to the flow of electrons. This is called Voltage Drop, for the electrical counterpart of pressure is known as Voltage, or Potential Difference. The total pressure (voltage) is spread right round the circuit from negative terminal to positive terminal of the PD, but it drops most across the resistance.

If the total pressure (voltage) put across the circuit was increased (like pumping the water harder), then the current flow through the circuit would increase—in other words, more electrons would move past a point in the circuit in one second. And this would apply to the current flowing through the resistance. And because the pressure was greater at the beginning of the resistance the drop in pressure along its length would be more—as the electrical engineer puts it, "There is a greater voltage drop across the resistance if the voltage across the circuit is increased."

Equally, a change in the "resistance" of the resistance would affect the current flow; the bigger it was with a fixed voltage, the smaller the current.

The relationship of the values of voltage, resistance and current in a circuit are defined in Ohm's Law, which is set out on the right.

If a number of resistances are connected one after the other in a circuit the full flow of current must pass through all of them, so although the resistance of each one may be different, and each "drops" part of the total circuit voltage according to its relative size, the total resistance offered to the voltage is simply the sum of their resistance. They are Resistances in Series.

But if the resistances are connected so they offer several different routes to the current, then each will take only part of the current flow. They will all, however, have the total circuit voltage across them. They are Resistances in Parallel. The formulae for calculating total resistance of a circuit are on the right.

Making a Usable "Potential Difference"

It is not particularly difficult to make electricity (*see the note on* Natural Electricity *on page* 138), but making it powerful enough to do work, and in sufficiently regular quantities to keep on doing the work smoothly, is not quite straightforward.

Two methods have been developed: the Chemical method, which ingeniously uses the electrical unbalance naturally occurring during certain chemical reactions; and the Magnetic method, by which mechanical

energy developed in a magnetic field is converted into electrical unbalance.

The Chemical method provides the batteries or dry cells (used in torches) and the accumulators (used in cars) with which everyone is familiar. They are both described on page 131, where chemical reactions involved are explained. The current flow from batteries and accumulators is a steady one in one direction, called Direct Current.

The magnetic method of producing electricity depends on the strange connection between a magnetic field and the electrical condition of a conductor lying or moving in that field. This is described more fully in the article on magnetism on pages 106–8. Electrical generators use some mechanical method (such as a steam turbine or a diesel engine—or even the drive of the fan belt of a car) to push a piece of wire, which doesn't have any electric current flowing in it, through the magnetic field of a strong magnet. The cutting of the lines of force of the magnet by the wire causes an *induced current to flow along it.* In other words, building a magnetic field round a wire makes an electric current flow along the wire, just as much as making an electric current flow along a wire produces a magnetic field round it.

In practice electric generators are more complicated than this (*see next page*) because as soon as we take the wire back across the magnetic field so we can bring it through again, the field is cut by the wire in the opposite direction, and this makes the electricity flow the other way. So instead of a straight piece of wire a loop of wire is rotated *mechanically* between the poles of a strong magnet. At the ends of the loop the rising and collapsing electric current is tapped off. The current from all electric generators flows first in one direction, then in the other. This is called Alternating Current. Though in some types (*see pages* 140, 206) it is possible to make the effect of the output of a generator have nearly the same steady current flow as a battery.

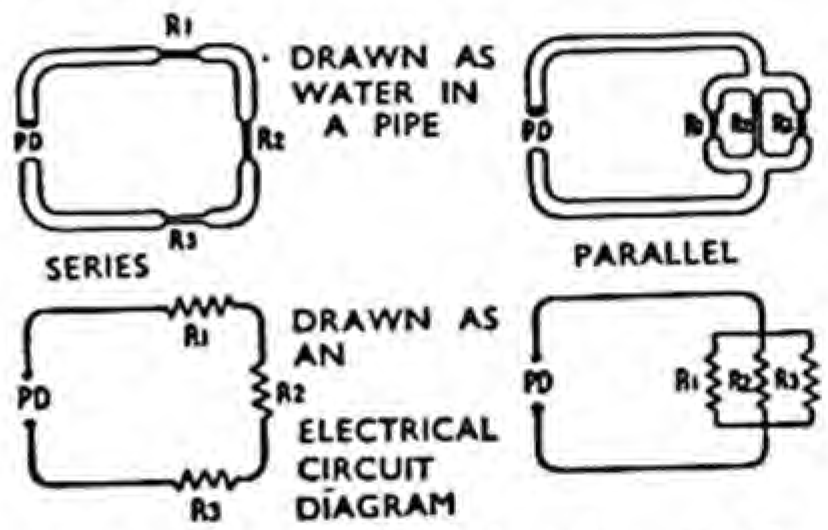
One thing about electric generators that puzzles many people is that the magnet in it is nearly always an *electro*-magnet, i.e. it does itself have electricity flowing through it. This is only a convenient use of the fact that when a conductor is made into a coil a magnetic field forms along the length of the coil whenever a current flows in the wire. A coil of wire with an electric current flowing through it has a north and a south pole just like a bar magnet. The chief difference is that the magnetic field of the coil increases in strength with the amount of electricity flowing through it, so a small *electro*-magnet can be made to have as great a magnetic force as a huge iron magnet.

Naturally it makes a lot of difference to the weight and ease of construction of an electric generator if its magnet is small rather than large. This is possible where the magnet is an electro-magnet, though a soft iron core is put in the centre of the coil to increase still further the power of its field.

Electric motors are only generators "in reverse". If a coil of wire with an electric current flowing through it has north and south poles, then it will turn its north pole as all magnets do towards the south pole of any other magnet near it, since unlike poles attract one another. So if a number of coils of wire are put between the poles of a magnet at different angles, and current is allowed to flow through each of them, each one will, while it is itself a magnet, twist round to put its north pole towards the main magnet's south pole. If all these coils are attached to one axle the result is an electric motor. Of course the coils will have to be specially arranged if the electric current put into them is not a straightforward one (i.e. alternating current). The design of electric motors is in practice an extremely complex business.

Resistances in Series and Parallel

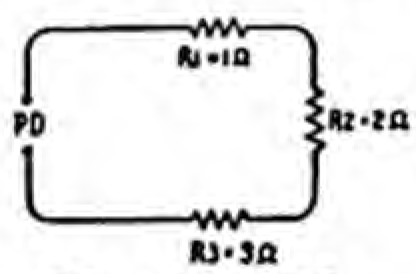
If an electric circuit is thought of as water flowing through a pipe, this is what a series circuit, and a parallel circuit would look like:



To calculate the total resistance of a number of resistances in series the formula is:

$$R_1 + R_2 + R_3 = R\ \text{TOTAL}$$

e.g.



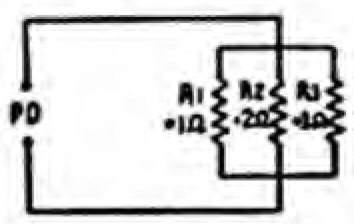
$$1\Omega + 2\Omega + 3\Omega = 6\Omega$$

The sign Ω stands for "ohms" (*see* definitions).

To calculate the total resistance of a number of resistances in parallel the formula is:

$$\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{R}\ \text{TOTAL.}$$

e.g.



$$\frac{1}{1} + \frac{1}{2} + \frac{1}{3} = \frac{1}{R}\ \text{TOTAL.}$$

$$\therefore \frac{6+3+2}{6} = \frac{1}{R}\ \text{TOTAL}$$

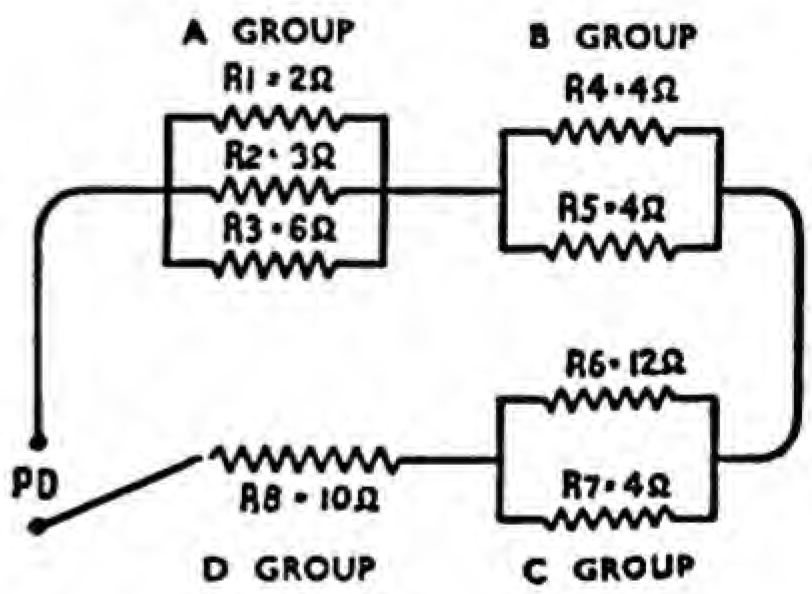
$$\therefore \frac{11}{6} = \frac{1}{R}\ \text{TOTAL.}$$

$$\therefore \frac{R\ \text{TOTAL}}{1} = \frac{6}{11}$$

Total resistance of parallel resistances is

$$\frac{6}{11}\Omega.$$

A combination of parallel and series resistances in a circuit is worked out by getting the total value of each set of parallel resistances first and treating each of those total resistances as a series resistance, like this:



OHM'S LAW

Ohm's Law states that in any electric circuit the current flowing is directly proportional to the potential difference across it; the voltage, the current and the resistance are all related to each other. The current rises as the voltage rises provided the resistance remains constant. When the voltage is constant the current rises as the resistance decreases, or falls as the resistance increases. The formula for Ohm's Law is:

$I = \frac{E}{R}$ (current = voltage divided by resistance).

I is current in amperes.
E is voltage in volts (or potential difference).
R is resistance in ohms.

This also of course means that

$E = IR$ (voltage = current multiplied by resistance)

and $R = \frac{E}{I}$ (resistance = voltage multiplied by current).

A convenient method of remembering all three is to put the three letters into a triangle like this:

 and blank off the one you want, so

 makes you remember $I = \frac{E}{R}$

and

 makes you remember $E = IR$

and

 makes you remember $R = \frac{E}{I}$

If any two values are known for a circuit the third can be found from the formula.

$$\text{A group} = \frac{1}{R} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6}$$

$$\therefore \frac{1}{R} = \frac{3+2+1}{6}$$

$$\therefore \frac{1}{R} = \frac{6}{6}$$

$$\therefore \frac{R}{1} = 1$$

A group totals 1Ω.

$$\text{B group} = \frac{1}{R} = \frac{1}{4} + \frac{1}{4}$$

$$\therefore \frac{1}{R} = \frac{1}{2}$$

$$\therefore R = 2$$

B group totals 2Ω.

$$\text{C group} = \frac{1}{R} = \frac{1}{12} + \frac{1}{4}$$

$$\therefore \frac{1}{R} = \frac{1+3}{12}$$

$$\therefore \frac{1}{R} = \frac{1}{3}$$

$$\therefore R = 3$$

C group totals 3Ω.

D group is a single resistance in series; it totals 10Ω.

Add all the group totals together as if they were four resistances in series:

$R = Ra + Rb + Rc + Rd$

$R = 1 + 2 + 3 + 10$

$R = 16$: the total resistance of the circuit.

Natural Electricity

Electricity can be produced by rubbing certain unlike substances together. A piece of amber or perspex briskly rubbed on silk for a few moments, and then brought near a tiny piece of paper will make the paper fly towards the amber and stick there for a short while and then fall off. This is because, by friction some of the atoms in the amber have become "unbalanced" through losing electrons to the silk. This produces a positive charge on the amber. The paper is attracted because an opposite negative charge is induced on it. The electrons which form the charge help to restore the electrical balance of the amber. When balance is again restored the amber has no further attraction for the paper and so it falls off. "Unlike" charges attract each other and "like" charges repel.

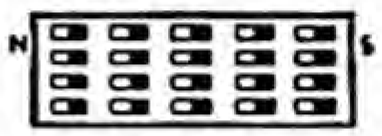
Lightning is another, but a very powerful form of static electricity. It is produced by very powerful upward air currents, which make up a thundercloud, in which the large raindrops get broken up and in the course of their rapid ascent become "positively charged". These charges accumulate until a very high potential is built up which discharges itself to earth or to another cloud, the discharge taking the form of an electric spark.

Permanent Magnets

If we bring the north poles of two bar magnets together they will "repel" each other. "Unlike" poles attract and "like" poles repel.

The Molecular Theory of Magnetism.

Unmagnetised bar of hard steel.

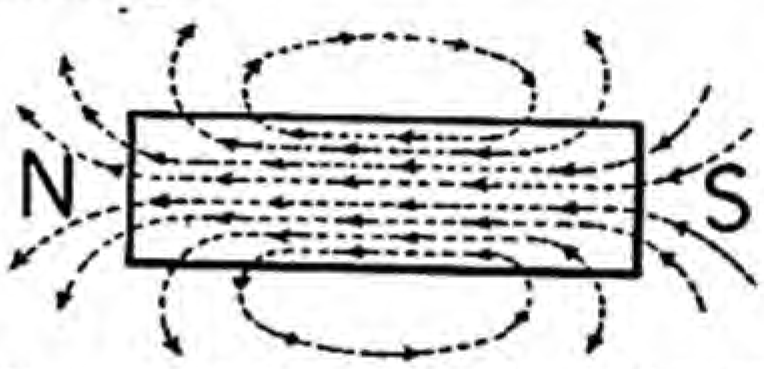


Fully magnetised.

The molecules have no definite alignment. Although each is a little magnet they cancel out and the steel is not a magnet.

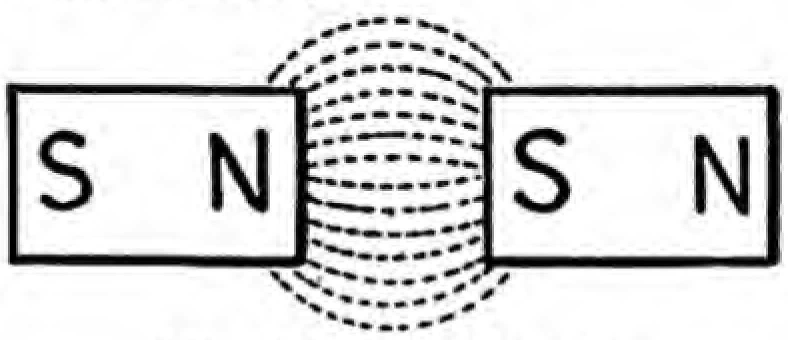
Right, they have taken up definite alignment, each one having its own polarity aligned with its neighbour.

When a substance is completely magnetised it is said to be saturated and no further magnetising will increase its strength.



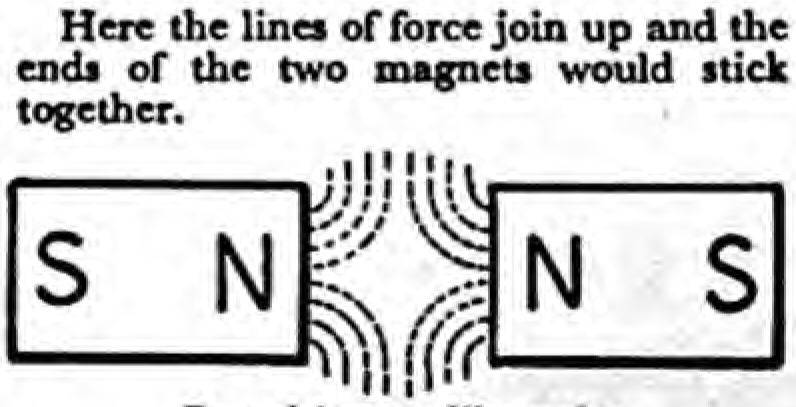
Bar magnet showing its lines of force or magnetic field.

The lines of force move outwards from the north pole in all directions and return to the south pole. This is due to the alignment of the metal molecules so that their like poles all point in the same direction thus giving polarity to the magnet as a whole. It must be particularly remembered that lines of force never cross each other and are never broken. If this were not so the practical development of magnetism in electrical engineering would not be possible. But they can be bent or directed by means of different types of apparatus. (*See* Electric Generators.)



Attraction = unlike poles.

Here the lines of force join up and the ends of the two magnets would stick together.

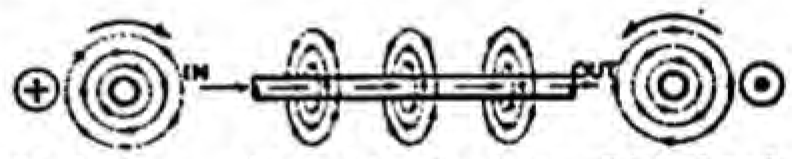


Repulsion = like poles

A point to be remembered about permanent magnets is, that they must not be over-heated or knocked about too much because it would weaken or destroy their magnetism altogether, in other words the molecules would be knocked out of alignment and return to the state shown in the first diagram of an unmagnetised bar of steel.

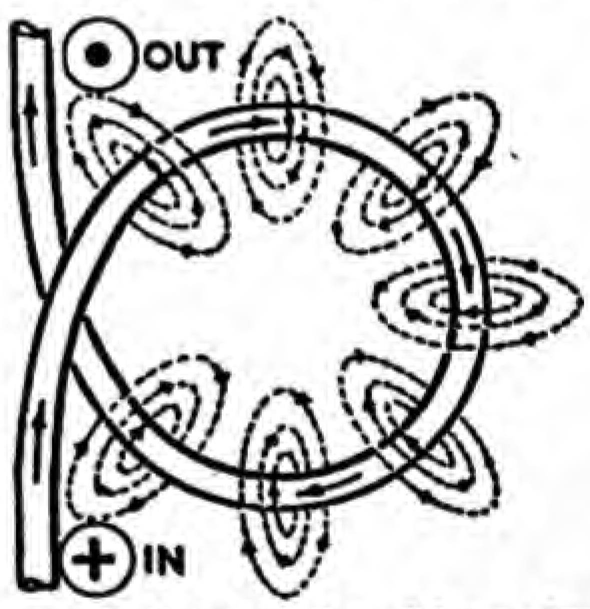
Electro-Magnets and the Motor Principle

Every conductor carrying an electric current produces a magnetic "field" about itself, the shape of the field varying according to the direction the current is flowing in the conductor. The strength of the magnetic field will depend upon the amount of current flowing at any instant of time. This is what happens to a magnetic field or "flux" in a current-carrying conductor:



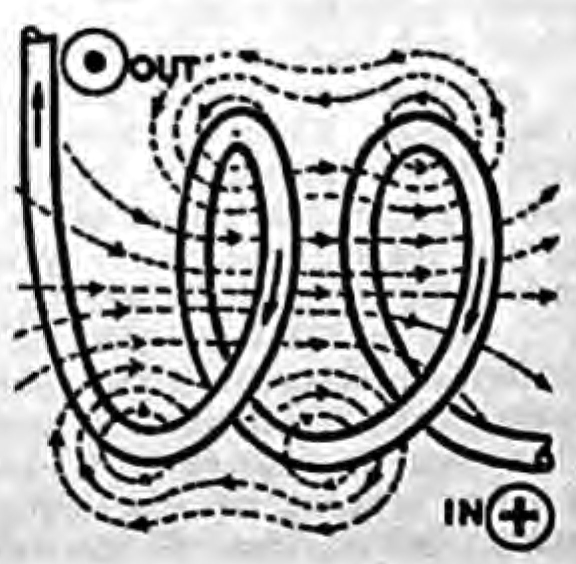
Looking at this end of conductor, current going IN. — Current flowing from left to right. Magnetic field in concentric circles much closer together than as shown. — Right-hand end view current coming OUT.

Now if the conductor is made into a "loop", the magnetic field looks like this:



Magnetic field produced by a single loop.

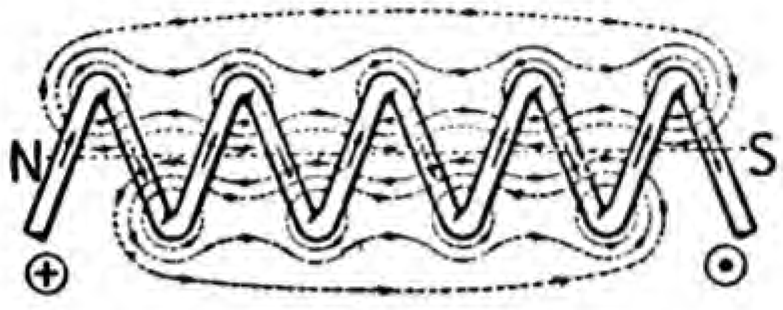
If the conductor is made into a coil the magnetic field looks like this:



The fields around the two loops merge and form a strong flux in the centre of the coil. A piece of iron or steel put into this coil would be held in suspension in the field.

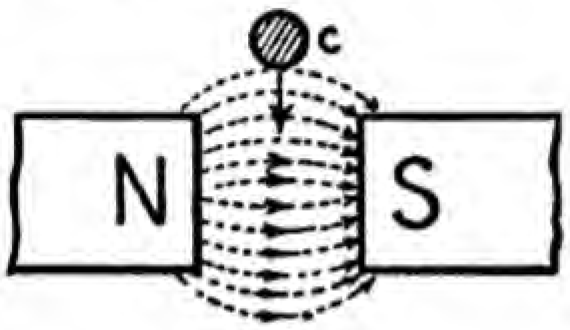
⊕ Denotes current flowing away from us and ⊙ denotes current coming towards us.

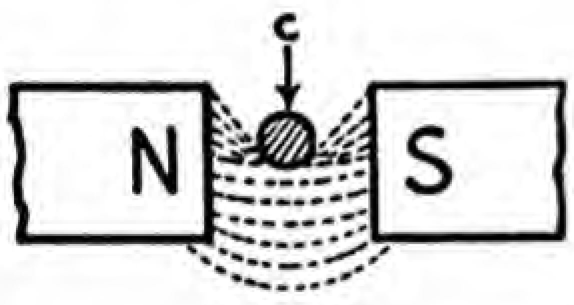
The more current through the conductor the stronger the electro-magnet becomes. Here is the side view of a coil conducting a currect of electricity showing how the lines of force run through the centre of the coil and have their greatest concentration there.

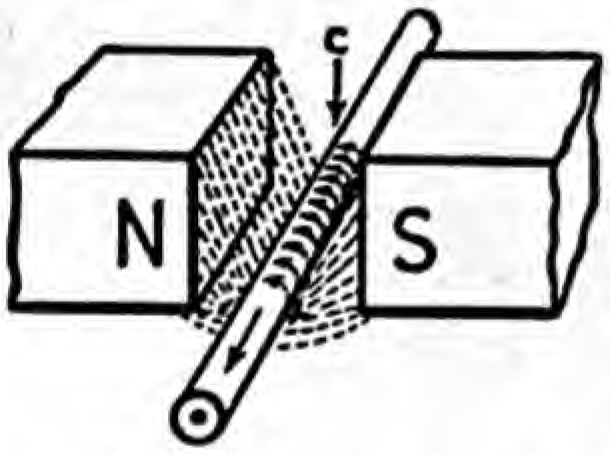


The polarity of an electro-magnet can be found by placing the fingers of the right hand around the coil pointing in the direction of current flow—the thumb will point to the north pole end.

Electricity is produced mechanically either by moving a conductor through a magnetic field, or by moving a magnetic field past a conductor.



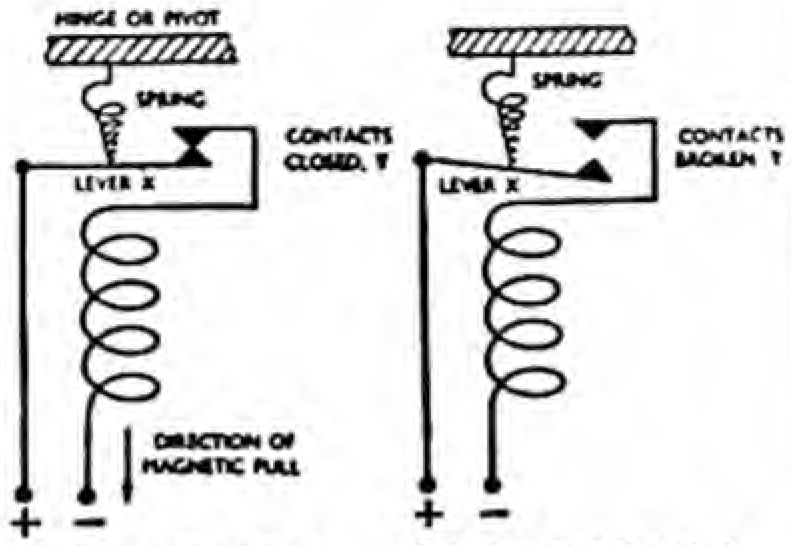




In the second of the three sketches the conductor is being forced downwards and the lines of force between the poles of the magnet are being bent around the conductor. Due to the greater concentration of flux on one side of the conductor and less on the other a magnetic whirl is set up in a counter-clockwise direction, so a current will flow in the direction shown in the third sketch. If we reverse the action upwards then the current will flow in the opposite direction. In both cases the effect around the conductor is the same as in the earlier sketch of the magnetic field, formed when electric current flows through a coil.

Solenoids

One very widely used development of the magnetic effect of a coil conducting electricity is in the SOLENOID. This has a lever of magnetisable metal at the north pole of an electro-magnet. As soon as a PD is applied to the circuit the coil becomes a magnet and pulls down the lever. The movement of the lever can be made to work a switch which cuts the coil's circuit to the PD. So current stops flowing through the coil, it ceases to be a magnet and the lever returns by spring action to its original position—this closes the switch again, returning current again to the coil, which becomes a magnet, and so on. In fact it goes on working the lever intermittently as long as the PD is available. A solenoid of this sort is used to ring doorbells and telephone bells (with a clapper attached to the lever and fixed so that it will strike a bell).



CIRCUIT COMPLETED AND FLOW OF ELECTRONS THROUGH COIL PULL DOWN LEVER X, THUS BREAKING CIRCUIT

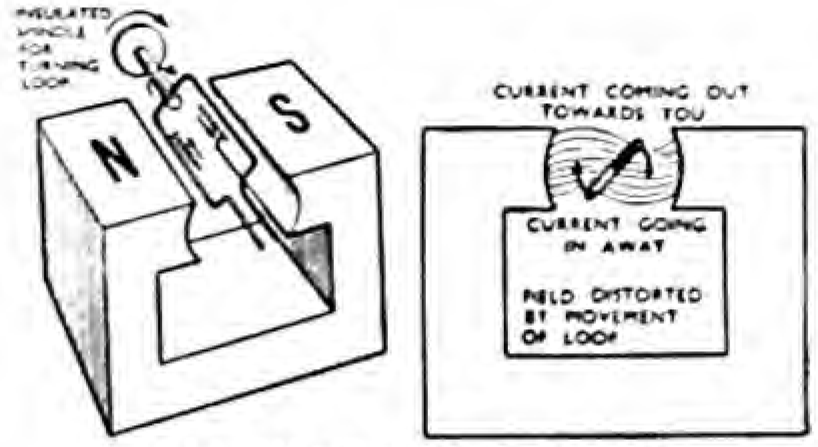
ONCE THE CIRCUIT COIL IS BROKEN THE COIL CEASES TO PULL DOWN LEVER X, SO THE SPRING PULLS IT BACK UPWARDS AGAIN TO MAKE CONTACT AT Y, THUS COMPLETING THE CIRCUIT SO THAT THE WHOLE PROCESS CAN START AGAIN

Of course the lever movement can be made to do other operations instead of breaking the solenoid's own supply circuit. It may operate a switch that brings into circuit one or more other solenoids—or it may shut off their supplies. Automatic telephone exchanges and traffic-light controls are worked by batteries of solenoids.

Electric Generators

Electricity is produced mechanically by a development of the motor principle mentioned in the note on Electro-magnets. This principle is that if a conductor is moved mechanically downwards through the lines of force occurring between the poles of a magnet, a current will flow through the conductor in one direction. If the conductor is then moved upwards through the lines of force a current will flow in the *opposite* direction.

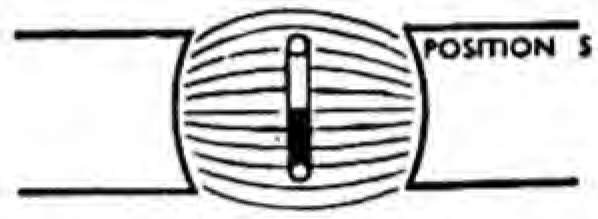
The basic design of electric generators is a simple development of this: the conductor becomes a loop of wire which is revolved between the poles of a magnet by some machine. For identification one half of the loop has been coloured white and the other black.



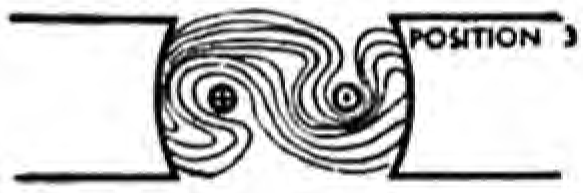
FIRST HALF CYCLE: POSITION 2

As the white half of the loop moves up the lines of force are bent and lap round the wire in a clockwise direction, inducing a current to flow in away from you. The black half of the loop moving down bends the lines of force too but gets them wrapped round in an anti-clockwise direction, so that a current is induced flowing towards you.

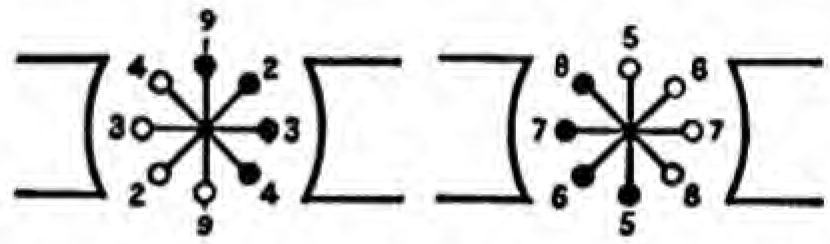
When the loop has moved round to this position neither half of the loop will be



cutting any lines of force and so none will be wrapped round the wire, and no current will be induced in either side. Of course this change happens gradually as the loop is turned. The greatest amount of current is induced when the loop is here and the

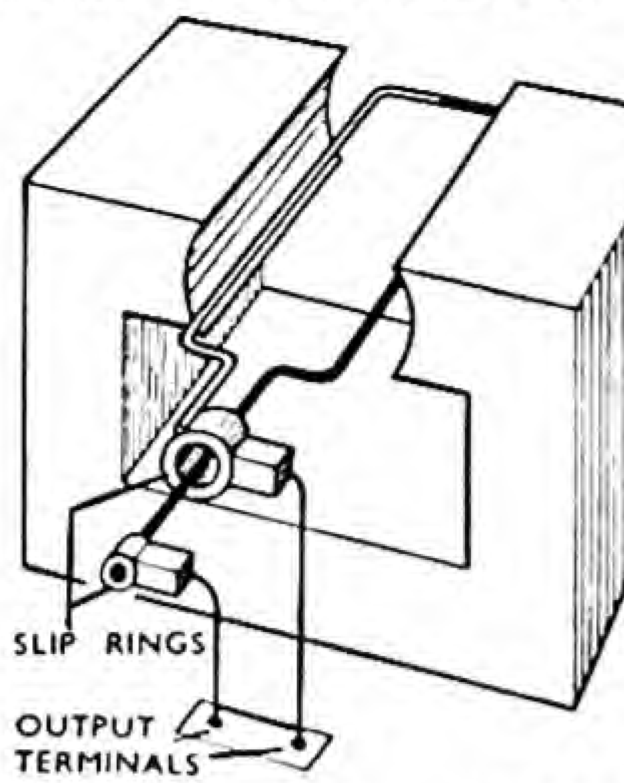


amount of current builds up from nothing at position 1 to maximum of position 3 and goes down to nothing again at position 5. Then as white starts to move downwards the lines of force wrap themselves round that half of the loop in an anti-clockwise direction,

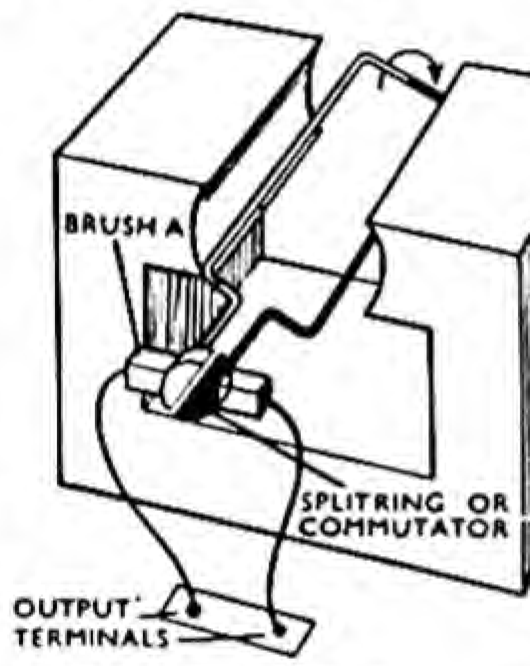


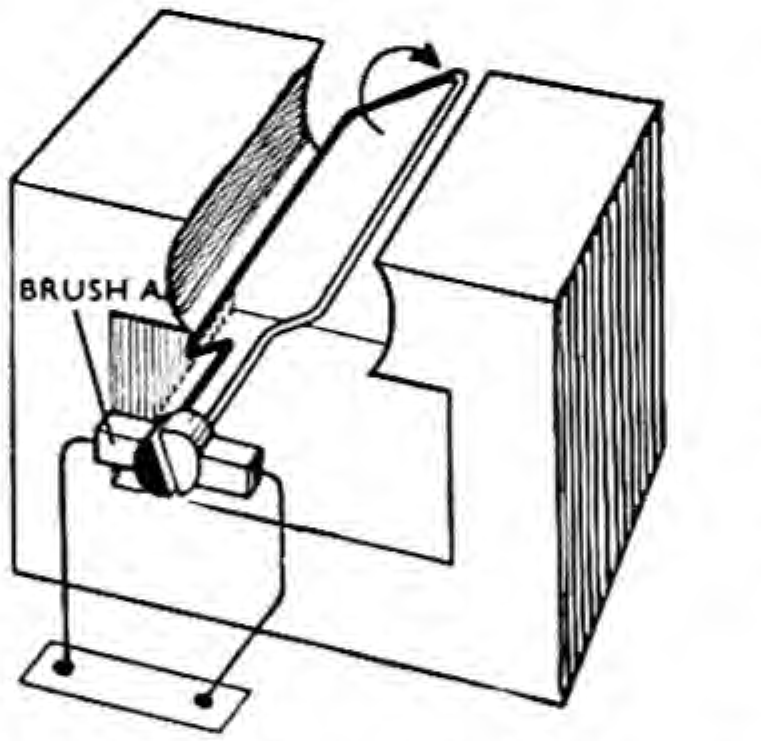
inducing a current flowing away from you. The black half of the loop reverses its current flow too, because it is now moving upwards. The current along the wire of the loop has reversed. A graph drawn of the result of one complete revolution of the loop looks

like this: from 1 it gets stronger in one direction to a peak at 3, fades away at 5, and builds up in the opposite direction to a peak at 7, dying away again by the time it reaches 9. This is known as 1 cycle of alternating current. The electrical engineer for convenience gives positions 1 to 9 on the graph as if they were degrees of a compass circle (and of course the loop itself is turning in a circle), 1 is 0°, 2 is 45°, 3 is 90°, 4 is 135°, 5 is 180°, 6 is 225°, 7 is 270°, 8 is 315°, and 9 is 360°, full circle.

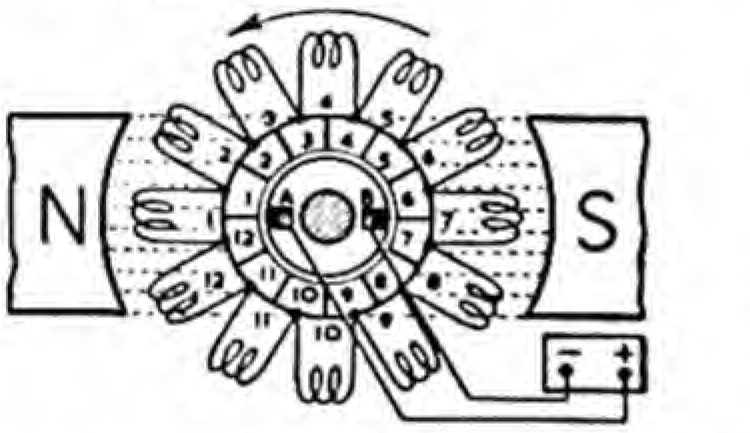


If *Alternating current* is required the generator is designed with separate "slip rings" attached to each end of the loop. Carbon brushes are held to rub against these and tap off the current. It is of course alternating (flowing first in one direction and then the other) just as it is in the loop.





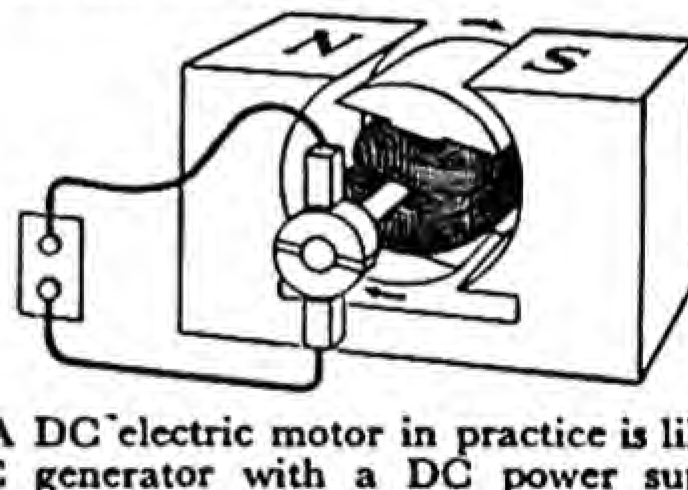
If *Direct Current* is required, that is current that only flows in one direction, the generator is designed with a split ring or commutator, half of which is attached to one end of the loop, and half to the other. Brushes are held in position one either side of the commutator, but because it is split in two semi-circles, brush A takes current from the white end of the loop during half of the revolution, then, the other semi-circle having come round, from the black half. This has the effect of making both halves of the cycle of alternating current in the loop flow through the brushes *in the same direction* as Direct Current.



Real electric generators have many loops so arranged that one of them is always going through the point where the greatest current is induced. The ends of the loops in the DC generators are each joined to a separate insulated segment of a commutator that has many segments. Loops are usually wound round a former of pieces of soft iron to increase the inductive effect. The magnet is an electro-magnet, with coils of wire wound round a centre of soft iron (again to increase the number of lines of force); the current flowing through these coils is tapped from the output of the generator itself in the case of DC generators.

Electric Motors

A coil of wire with a current flowing through it becomes an electro-magnet with north and south poles. Two magnets put together tend to turn so that their opposite poles line up. If therefore an electro-magnet is hung on a spindle between the poles of another electro-magnet, it will naturally swing round until its S pole faces the N pole of the outer magnet.



A DC electric motor in practice is like a DC generator with a DC power supply feeding into the brushes. Its armature (electro-magnet) is a soft iron former with many turns of wire round it. The main magnet is also an electro-magnet.

Definitions

Specific Resistance. The resistance between opposite faces of a centimetre cube of a material. This varies considerably according to the material. From the known specific resistance of a material, S, the resistance of a conductor made from it can be calculated.

$$R = \frac{Sl}{A}$$

where l is the conductor's length in cm., and A is its cross-section in sq. cm. For a circular wire the value of A will be $\pi \times \text{radius}^2$.

Gauss. The unit of measurement of the intensity of a magnetic field. A magnetic field is of one Gauss intensity when it acts with a force of one dyne on a unit magnet pole. The intensity of a magnetic field is represented diagrammatically as one line of force per square centimetre of the cross section of the field for every Gauss unit, so 10 Gauss would be considered as 10 lines of force in 1 sq. cm.

Law of Inverse Squares. Magnetic attraction or repulsion by one magnetic pole on another varies inversely as the square of the distance between them.

The same law applies to all radiations, light (*see pages* 113–19), heat, radio waves, etc.

Ohm. The unit of measurement of resistance. Its symbol is the Greek letter Ω (omega). One Ω is the resistance of a column of mercury 106·3 cm. long and 1 sq. mm. in cross section at 0°C. temperature.

Dyne. A unit of measurement of force of the C.G.S. system (Centimetres, Grammes, Seconds). One dyne is the force which acting on a mass of 1 gm. will give it an acceleration of 1 cm. per sec. It is a very tiny unit. A force of 1 gm. weight is g dynes (where g is the acceleration due to gravity), i.e. a force of 1 gm. = 981 dynes.

Erg. The unit of measurement of work done. When one dyne acts through a distance of 1 cm. in the direction of the force one erg of work is done. A more practical unit is the *Joule*, which is 10,000,000 ergs (10^7 ergs). One joule is the amount of work done when a 1-ampere current flows through a 1Ω resistance for 1 second. It is approximately ¾ ft.-lb.

Coulomb. The unit of measurement of the quantity of electricity flowing in a circuit. When a 1-ampere current flows for 1 second the quantity of electricity passing is 1 coulomb. *See also* Electrolysis.

Joule (see *Erg*).

Volt. The unit of measurement of electrical pressure. The potential difference between two points is the work done in ergs (*see* Electro-static units) in moving unit positive charge from one to the other. One volt is $\frac{1}{300}$ of an electrostatic unit of potential difference. It is also the potential difference between two points when 1 coulomb passes between them and 1 joule of work is done. *See also* Ohm's Law.

Electro-static Units. Just as the North poles of two magnets repel each other, so two objects which are both positively charged repel each other. If a body is positively charged, and a unit positive charge is brought from infinity up to it against the mutual repulsion of their charges, and the amount of work done in moving it is 1 erg, then the potential at the first body is 1 E.S.U. *See also* Volt.

Electro-magnetic Units. Relate the flow of current in a coil of wire to the strength of the magnetic field set up in the coil. One E.M.U. of current is the current that has to flow through a wire 1 cm. long and coiled as the arc of a circle whose radius is 1 cm. to produce a magnetic field at the centre of the circle of 1 gauss strength, or to exert a force of 1 dyne on unit magnet pole placed at the centre of the circle.

Unit Electric Charge (electrostatic) is the charge which exerts a force of 1 dyne on an exactly equal charge placed 1 centimetre from it in air.

Unit Magnetic Pole is that pole which is repelled by a force of 1 dyne by an exactly equal pole 1 centimetre away from it in air.

Electro-motive Force is the total Potential Difference that an electric cell or battery can produce. It is the Potential Difference between its terminals when no current is delivered by the cell (an "open circuit").

Ampere. The unit of measurement of current flow. It is $\frac{1}{10}$ of an Electro-magnetic Unit. It is also defined as the steady current which in 1 second passing through a solution of silver nitrate in water will deposit ·001118 gr. of silver (electrolysis). *See also* Ohm's Law.

Watt. The unit of measurement o power used or needed in an electric circuit. One watt is one joule per second. In any circuit in which E volts potential difference causes Q coulombs of electricity to pass the work done in the circuit is EQ joules. As the coulomb is current (I) × time in seconds (t), EQ can be expressed as EIt. One volt is the PD when 1 coulomb passes and 1 joule of work is done (*see* Volt). So if EIt joules of work are done in t seconds, then EI joules are done in 1 second, i.e. the power is EI watts. Watts = Volts × Amperes.

Note: EIt can be expressed—Ohm's Law E = IR as IRIt or I^2Rt (*see also* Mechanical Equivalent of Heat).

An electric lamp is marked 240 volts, 60 watts: therefore the current will be

$$I = \frac{W}{V} = \frac{60}{240} = \frac{1}{4} \text{ amp.}$$

Mechanical Equivalent of Heat. The heat generated in a circuit by a current I flowing through it is proportional to the resistance R, the time t, and the square of the current: Heat = I^2Rt. If I is in amperes, t in seconds, and R in ohms, the heat energy is found in joules. Calories are the physicists' usual measure of heat (*see* p. 51), and it has been experimentally checked that 1 calorie = 4·2 joules (this proportion is known by the symbol J), so

$$\text{Heat} = \frac{I^2Rt}{J} \text{ calories.}$$

CHEMISTRY AND LIFE

Life is a business that has very much to do with chemicals. Indeed without chemicals and their constant change by interaction with one another life would not be possible. Whenever we come upon living activity we find it occurring in the presence of protoplasm. Protoplasm is a mixture of chemicals, some of them very complicated, dispersed in a large amount of water. Water in fact makes up the largest part of any living tissue. Up to 80 or 90 per cent of an animal or plant may be composed of water.

In this water tests reveal the presence of very small amounts of the salts of various metals. This is as true for the sap of a plant as it is for the serum of an animal's blood.

In addition, dissolved in the watery solutions found in the bodies of living creatures we find other substances. Sugar is readily soluble in water and is found in plant sap (up to 19 per cent) and in blood (up to 0·1 per cent). Starch and a substance called glycogen are both chemically akin to sugar. But being insoluble they are chiefly used for storage. Starch is found in the plant world, for example in the tuber potato, and glycogen is the storage substance in the animal world, as in the liver of many creatures.

Fats may also be found being used for storage, as in the oil rich castor oil bean, or in the blubber of whale, where the fat is not only the means of storing energy but serves as an insulator against undue loss of heat to the surrounding cold water. The fat of land animals including man also has this double function.

Almost all the remaining part of protoplasm is composed of those substances known as proteins, about which more will be said later on.

The Chemical Differences Between Plant and Animal Feeding Processes

One of the principal differences between plants and animals has to do with the chemistry of their feeding.

Green plants are self-sufficient for their food provided they receive sunlight and have contact with air and with mineral salts and water, the last usually coming to them from the ground. Given these supplies, their chlorophyll containing tissues can manufacture sugar, from which in turn are formed starch, fats and proteins (*see pages* 36, 37).

In contrast, the animal is not self-sufficient, being wholly dependent upon plants for its necessary food. This is true whether it is a herbivore feeding directly on grass or corn, or is a carnivore eating the body of some other animal which in its turn, if it is not itself a herbivore, will when its food chain is traced backwards be found to have been dependent on grass or other vegetable food for its feeding. The tiger eats the zebra, the zebra eats grass. The herring eats animal plankton in the surface waters of the sea but the animals of this plankton have themselves eaten little one-celled plants (or diatoms) that are also in the plankton.

So it is seen that chemical changes underlie the basic activity of living things: that of feeding. But the actual chemical processes involved differ according to the kind of creature we are studying.

Man and his Food

We will now look a little more closely at the feeding of man, his requirements as an animal and the way in which those needs can be satisfied.

Food can be thought of in terms both of quantity and of quality. We will take quantity first.

The need of a man for food is measured in heat units, or calories. Calories can be converted into mechanical energy units quite easily, whilst being the most convenient and practical units in which to measure both the need of an animal for energy, and the energy value of its food. An account of this is given in the article that has to do with animal feeding and calorimeters (*see page* 70).

The food need in calories of a man varies very much with the kind of work he does. It is equal to his energy losses measured as heat, during resting and working. These can be measured scientifically and may range from 2,500 calories per day to as much as, say, 5,000 calories per day according to whether his work is light (clerical) or heavy (shifting great weights). The value in calories of what food he eats is also discovered by scientific experiment, burning samples of the food with oxygen in a closed chamber called a calorimeter and measuring the amount of heat given out in the process. The result is expressed in calories per unit weight of the

food tested. You can buy books in which there are tables showing the fuel value to you of a particular food for every ounce or gram eaten. If you know all that you have eaten in 24 hours, calculation will then enable you to find its value in calories. Fuel foods having high caloric value are sugar, starch, fats and oils.

Does it Matter What We Eat?

But to have had enough food does not ensure that you have had the right food. So we must now look at this question of quality. You cannot live by eating the straw or hay that could nourish a cow because you have not the digestive system to deal with these things and make them available to you. It is also true that many of the things you can digest may be insufficient in their composition to sustain your life, though they may be satisfactory in checking your hunger.

The chemist divides the constituents of the foods that we eat into three main categories.

CARBOHYDRATES. These (they are not hydro-carbons, which include paraffin and petrol, despite the similarity of name) are compounds of the element carbon with hydrogen and oxygen, the last two being present in the same proportions as they are in water; hence the name carbohydrate. Carbohydrates are burnt as fuels in the body when some of the energy produced can be used by the muscles in doing work. Carbohydrates include sugars, of which there are a great many different sorts, starch and glycogen. As starch and glycogen are not soluble they have in the course of digestion to be turned into sugars so that they can be absorbed into the body through the wall of the gut.

FATS. Fats are compounds of glycerine and a series of substances called fatty acids. Fats are indeed turned into glycerine and fatty acids in the course of digestion. These products are water soluble and can pass through the wall of the gut into the body. Like carbohydrates fats serve only to give us energy.

PROTEINS. These are the third sort of food chemicals needed by the body in relatively large amounts. They are most complicated to understand, being compounds of nitrogen in the form of long chain-like molecules made up out of diverse nitrogen-containing amino-acids. Proteins are broken down into these soluble acids in the course of digestion in order to pass into our bodies. Different proteins are obtained from the bodies of different kinds of animals, i.e. are *specific*. The proteins of an ox or a cow are quite different from the proteins of a man. In the course of digestion the necklace-like molecules of protein, having been broken up into their component amino-acids (the beads), our bodies receive these beads and then string them together again into our own specific human proteins. As a result our bodies can grow or be repaired as may be necessary. Proteins besides being used for growth and repair can be used by our body for fuel after they have undergone a destructive process which splits off the nitrogen as ammonia (later turned to urea) and leaves behind substances which can be burnt as fuels.

The principal sources of proteins in our food normally contain a considerable amount of water, so much so that if you need to consume 3½ oz. of protein it may involve you eating as much as a pound of steak or some other equivalent natural source of protein.

Milk (where the proteins are present with sugar and fat), cheese (made from milk), eggs (where proteins and fats are together), and meat or fish are the sources from which proteins are most readily obtained, though they can also be obtained from plant sources as well. The seeds of beans and peas, nuts and whole cereals are all useful vegetable sources of protein.

One of the most concentrated sources of proteins is milk powder. Here the water has been removed by dehydration, leaving the milk solids which are rich in protein and balanced with fat, sugar and salts. This is why they are used as baby foods.

The above groups of substances—carbohydrates, fats and proteins—are all needed daily in sizeable amounts. The amounts can be determined by experiment and calculation. Recommendations may vary from case to case depending on body weight, age, sex and living conditions, but the amounts involved are in the region of ounces per day.

A Little of These Goes a Long Way

Other items in our necessary lists of food are needed in much smaller amounts. They are spoken of as the accessory food substances. They include the mineral salts needed for growth and repair of the body. Here the amounts involved are only parts of an ounce per day. Calcium and phosphorus, needed for building teeth and bones, are needed at the rate of about $\frac{1}{30}$th of an ounce of each per day. Similarly, iron, for blood making, iodine for the secretion of our thyroid glands and other elements are needed in regular but small amounts. These food minerals can be obtained from the vegetable part of our diet, and from dairy produce such as milk, eggs and cheese.

Most recent of all to be recognised as necessary chemicals in our food were those which are needed in such tiny amounts that it was long before they could be certainly detected and measured. The needful amount may be as little as a 1,000th of an ounce per day down to as little as 1,000,000th of an ounce per day depending on the particular substance. In this group we find those mineral salts which are spoken of as trace elements because of the smallness of the amounts in which they must be had. Copper, cobalt, manganese and zinc, in the form of their salts, are needed in this way by our bodies for our health.

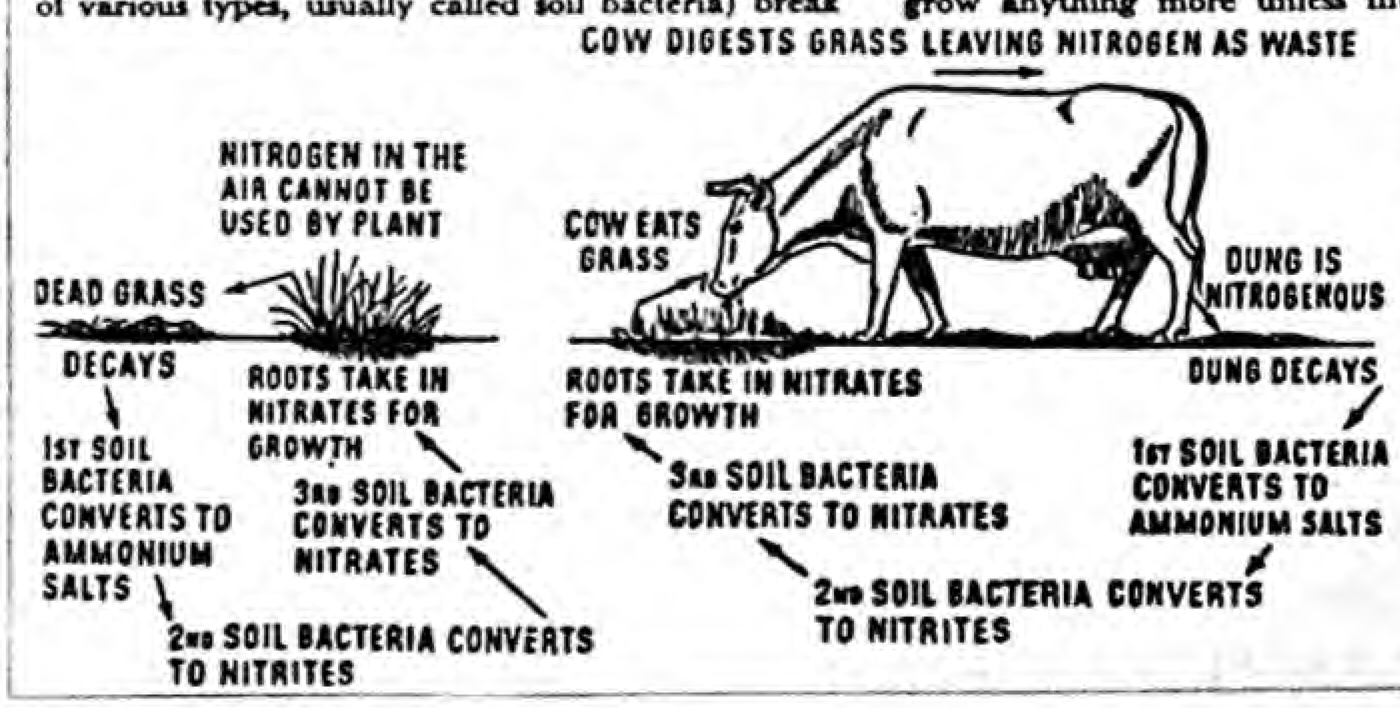
It is here among the accessory foods that we find the vitamins. Though they are only needed in the most minute amounts the quantity of each that is required is definite if health is to be preserved and growth, in the younger person, to be maintained. Without them being present in the diet, as is shown by feeding laboratory animals on purified diets of carbohydrate fat and protein, the animal fails to do well or may even die.

Too many vitamins are now known for us to deal with them in any detail. They go into one or other of two groups, those which are soluble in water (found especially in vegetable foods, in milk and in liver) and those which are soluble in fats (found principally in dairy produce, in liver and sometimes in the germs of seeds like the germ of whole cereals).

Thus are we made out of the chemicals of the earth and of the air! These are presented to us as our food whether animal or vegetable, are dismantled in digestion, and reconstructed into ourselves by the chemistry of the body.

THE NITROGEN CYCLE

Growing plants need a great deal of nitrogen, yet they are not able to extract it from the air, as they do carbon dioxide. So it is raised through their roots from the soil as nitrogen salts (nitrates) as described on pages 36, 37. Why doesn't the soil run out of nitrates? Because when the plant dies it "decays"—that is, microscopic organisms (bacteria and protozoa of various types, usually called soil bacteria) break up its proteins first into ammonia and ammonium salts; other soil bacteria then oxidise these into nitrites; different types of soil bacteria still oxidise the nitrites into nitrates. The cycle is complete, the dead plant has become food for a living plant. If the dead plant is taken away and not allowed to decay into the ground (when a farmer reaps corn, for instance, or a cow eats grass) the soil will soon not grow anything more unless nitrates are put back into it. This can be in the form of natural nitrate (e.g. Chilean saltpetre), or chemically made nitrate salts (see sulphuric acid, p. 129), or as the dung of the cow, for this manure is very nitrogenous, as is the excreta of any animal (including man) which has eaten a plant-eating animal. In the same way dead bodies decay and return nitrogen to the soil.

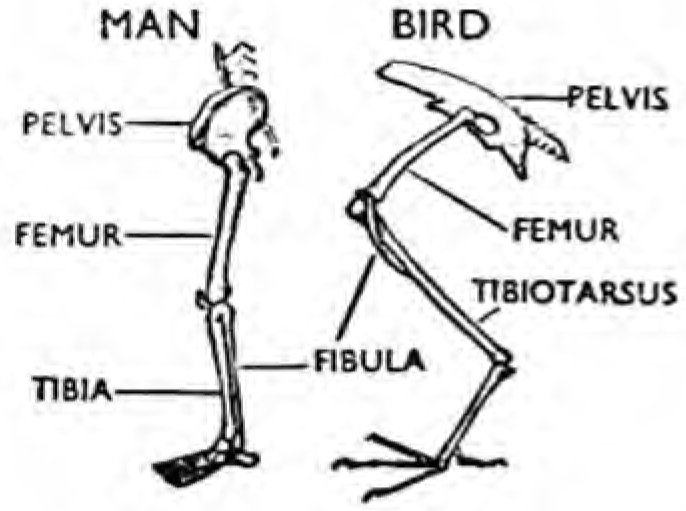


THE STRUCTURE OF ANIMAL BODIES

The chief problems that face an animal are to secure food, absorb it and then get rid of the wastes. It must act so as to achieve these ends and avoid its enemies.

For most animals the search for food involves moving about. This is called locomotion. To this end there is usually a skeleton. In the vertebrate it is made up of rods hardened with lime salts upon which elastic muscles work like levers, so changing the shape of the skeleton and causing movement. In the fish, movement through the water is obtained by swinging the tail from side to side as a result of muscle contractions operating on the backbone. The fins are not used for propelling the fish, merely for balancing it. Flight in the bird results from wing beats brought about by contraction of the breast muscle pulling down the wing bones. Thus by swimming or running, leaping or flying, the animal is able to pursue its food.

Other more lowly animals have the skeleton on the outside of their body structure and move their jointed limbs by the contraction of muscles that are within the skeleton. This is true of crayfish and cockroach. They are called invertebrates, as they have no backbone. The crayfish is somewhat unusual in having a small amount of internal endoskeleton to which is attached the front end of the main muscle mass of the tail. The skeleton in crayfish and cockroach is a horny structure made of a substance called chitin, somewhat similar to the material of our hair. In snail the exoskeleton is composed



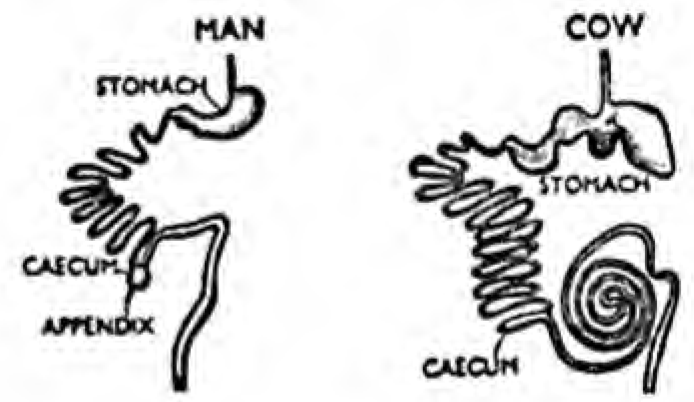
of lime salts and serves more as a place of refuge to the animal, not being involved in bringing about locomotion. Muscles attached to the centre column of the shell enable the body to be withdrawn within its spiral chamber.

Where a creature's skeleton is external, it creates problems in connection with growth. In snail the coil is lengthened and enlarged by the secretion of more lime salts from the margin of the fleshy mantle with which it is lined. Crayfish and cockroach shed their skeleton at successive moults. Each moult is called an acdysis. After moulting, while the skeleton is still soft, they grow rapidly until hardening again prevents further growth.

The worm is an invertebrate with no visible skeleton on which its muscles may act to bring about movement, but there is nevertheless something on which the muscles can act or pull in that the worm's body cavity is full of a compressed fluid against which the muscles act. Rhythmical contractions travel down the length of the worm's body. The expanded parts of the body are fixed momentarily against the ground by projecting bristles so that the result is forward movement of the animal, as the muscular contraction passes down the length of the body.

Somewhat similar action results in forward movement on the part of the snail. In the insect, as in the bird, flight is by means of wings. These are attached to the external skeleton of two of the thorax segments. Two muscle masses contracting alternately change the shape of these segments rhythmically thus causing the wings to rise and fall very rapidly.

Digestion involves the taking to pieces of the needed substances in the food so that the products may pass through the body wall of the animal into its tissues. The alimentary canal or gut, though inside the animal, is really part of the outside world. When an animal swallows it wraps itself round its food ! The food is forced along the canal by waves of contraction, and at various points during its journey digestive juices are mixed with it. The result is a fermentation setting free much simpler chemical substances, like sugars and glycerine and amino acids. These being soluble pass through the extensive wall of the intestine and into the bloodstream that carries them away to the liver.

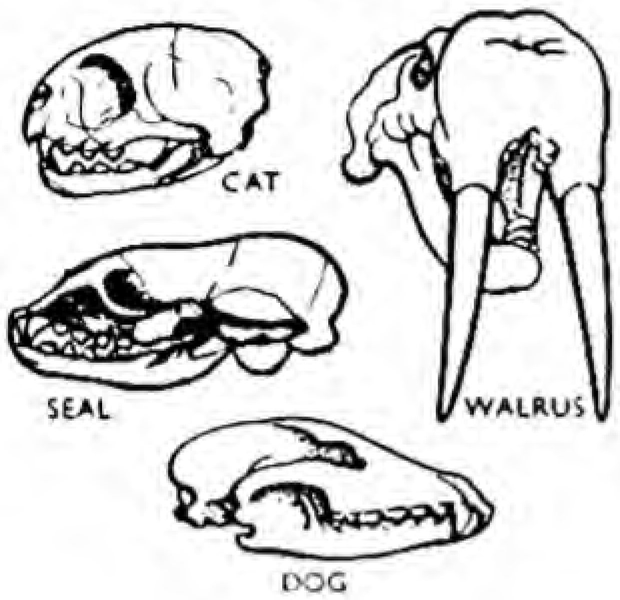


All that resists digestion is ultimately excreted at the far end of the canal as solid waste. Plant-food material is very resistant to the process of digestion because so much of it is cellulose (the substance of which paper is made). Thus herb-eating animals often have complicated stomachs and very long intestines to enable more complete digestion of the cellulose which, for them, can be a food, though to us it is useless. (You cannot live on a diet of hay or straw.) Meaty substances digesting more rapidly can be dealt with by a shorter length of intestine. Man being an omnivore has a gut of intermediate character, in this resembling rat and pig.

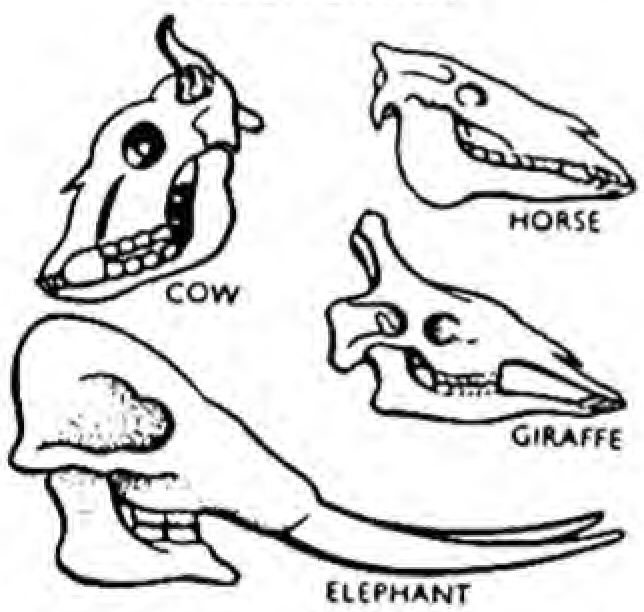
Where food is hard or tough it

must first be chewed or ground, either by teeth in the mouth or, as in bird, cockroach and worm, by a milling process carried out in the stomach which here is a gizzard in which grinding with stones reduces the food to pulp.

FLESH-EATERS



HERBIVOROUS

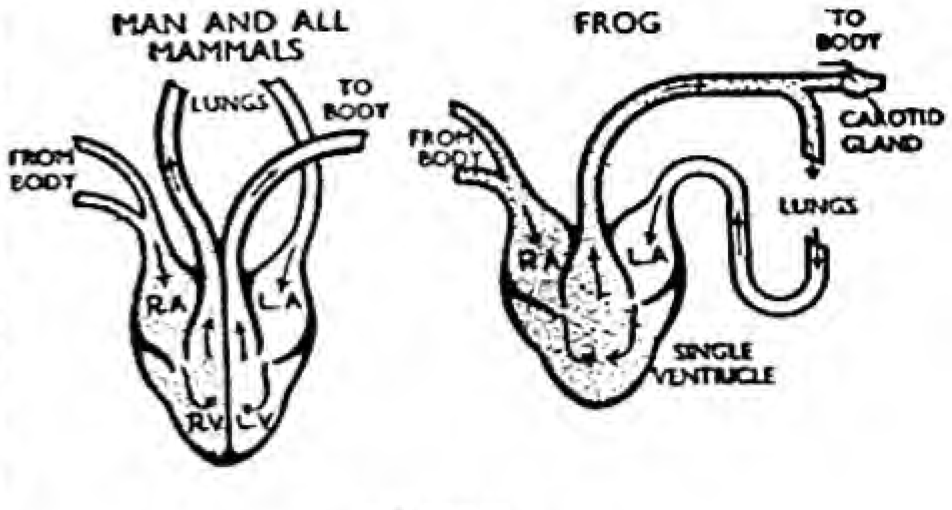


The muscular actions involved in movement and digestion must be fitted together into a pattern if the result is to be effective or purposeful. The alternative could be chaos. This fitting together, or co-ordination, is brought about by the nervous system which is a signalling device prompting the action of every muscle and fitting its action into a complex response to stimuli coming from the outside world. These stimuli are picked up by creatures' sense organs.

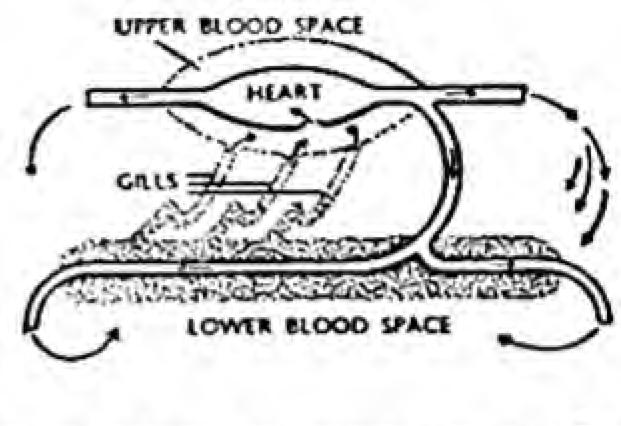
The products of digestion are carried round the body in solution, usually by a bloodstream, which is kept in motion by the pumping action of the heart. In the body the food not used for growth is burnt up as a source of energy to make further movement possible. (You use up some of your breakfast in looking for your lunch !) For this burning of food oxygen is necessary, and the bloodstream is usually also the means by which this oxygen is brought to every cell in the body. Oxygen is picked up from the outside world through the thin walls of a lung membrane in contact with air or of a gill immersed in water. It passes directly into the bloodstream through the capillaries. One result of burning food in the body is the production of water soluble wastes—carbon dioxide and compounds of nitrogen. These are carried away by the bloodstream. Carbon dioxide is excreted by the lungs (gills) urea, a compound of nitrogen, by the kidneys.

In a creature like the insect, where oxygen is taken through tubes directly into the deeper parts of the body, the blood has only to serve for the carrying of food. It therefore need not move so rapidly or so efficiently, and you will see that the insect has a most simple kind of circulatory system. In the crayfish the heart is a tube lying in a dorsal blood space containing venous blood which is sucked into the heart through valves. Contractions drive blood out at each end—that is to say, forwards and backwards through vessels which deliver it to the distant parts of the body. It ultimately drains back into a large central blood space beneath the body from which it is drawn up again to the blood space round the heart, somewhat in the manner of oil pumped through a motor-car engine from the sump.

In the backboned animals the heart can be of varying complexity. In the fish, with its single loop circulation, it is a two-chambered muscular organ pumping the blood forward to the gills. This is also the case in the frog tadpole, but the adult frog has lungs instead of gills, and a three-chambered heart instead of a two-chambered one. The diagram shows how there is a double circulation through the ventricle of this three-chambered heart. On the first occasion the blood is mostly sent to the lungs, and on the second occasion mostly to the body. The



CRAYFISH

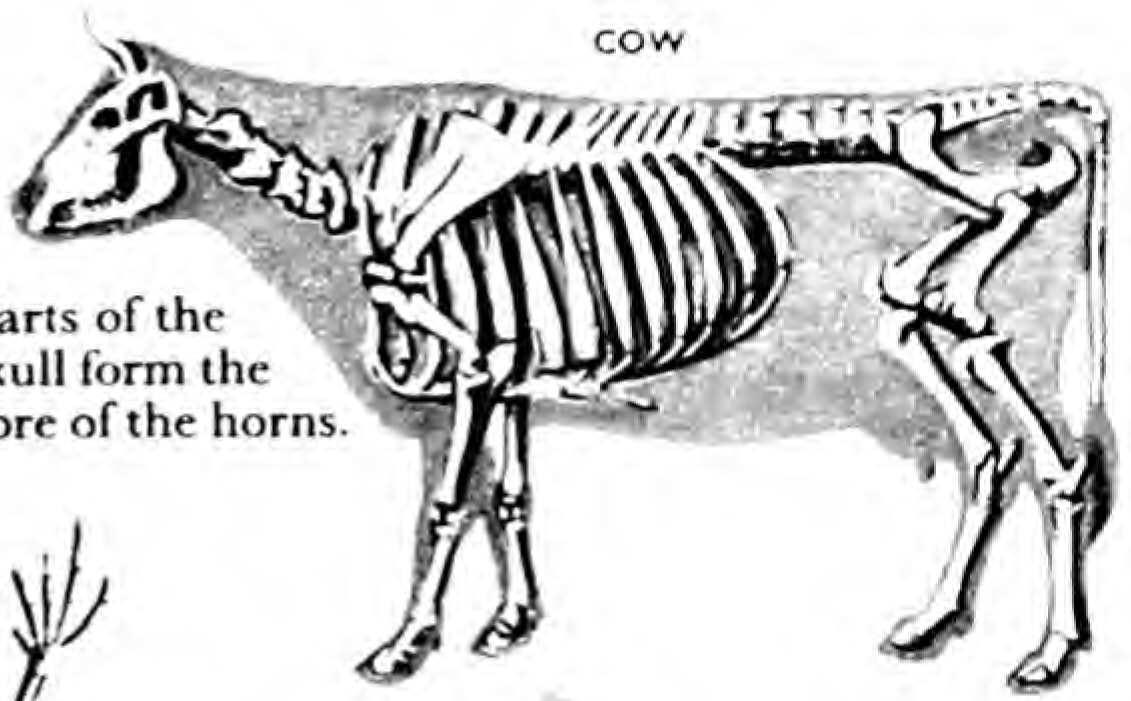


most efficient arrangement for circulating the blood is a four-chambered heart as found in the birds and all the mammals. Here the right side of the heart pumps spent blood to the lungs, whilst the left half of the heart draws blood from the lungs and pumps it to the body.

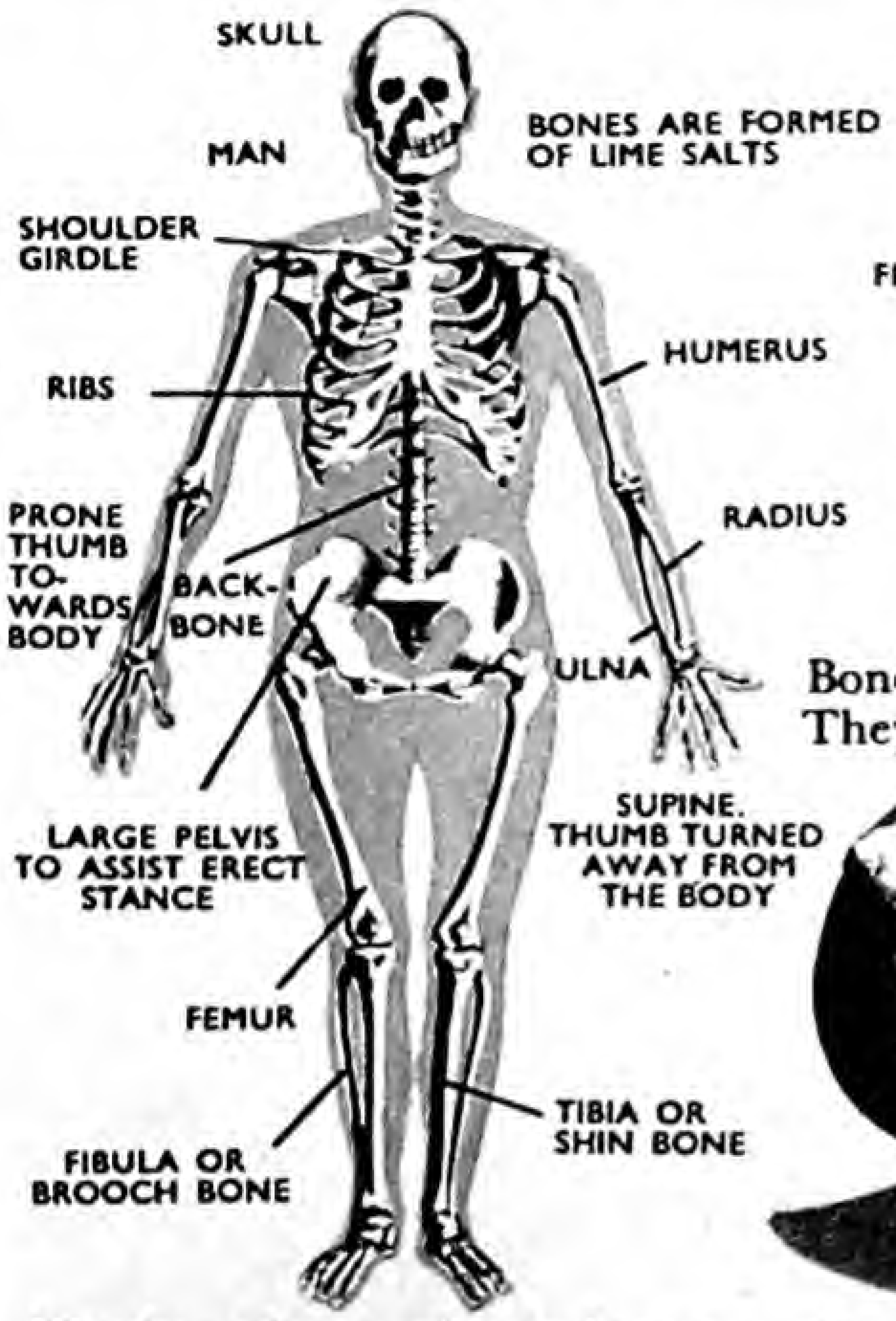
Both gills and lungs exchange gases between the animal and its surroundings through wet membranes. In the bird there is a very rapid consumption of oxygen during flight which could not be met by the blind ending lung found in other vertebrates. The lung cavity is carried backwards as a series of air sacs housed in the bones. Thus the air is first drawn right through the lung and then shot out again through it with great rapidity. Associated with their enormous oxygen demands birds have a very high rate of heart beat, sometimes so rapid that the eye cannot follow it; up to 1,000 beats per minute being known. Oxygen demands in the flying insect are met by the extensive tubular system which conveys air right into the depths of the body and so to the muscles. In the snail a cavity beneath the mantle is lined with a wet lung-like surface. In the worm the lung surface is the wet surface of the body. Gases cannot be exchanged at all rapidly through a dry wall, hence the necessity for the respiratory surface of land animals to be kept moist by secretion from the body.

The Skeleton

This is the bony part of the body and in man is internal with the fleshy parts surrounding it. Invertebrate creatures have their skeleton on the outside with the flesh inside. Some creatures have no hard skeleton at all.



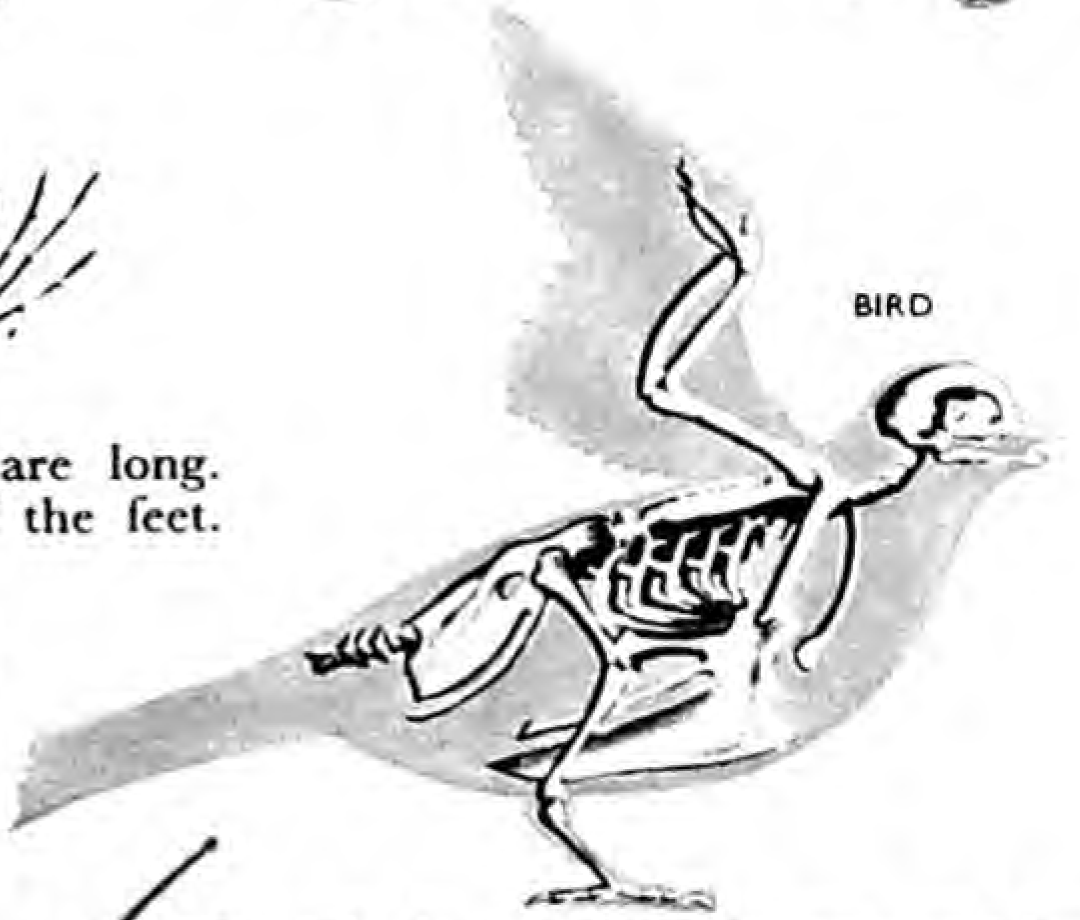
Parts of the skull form the core of the horns.



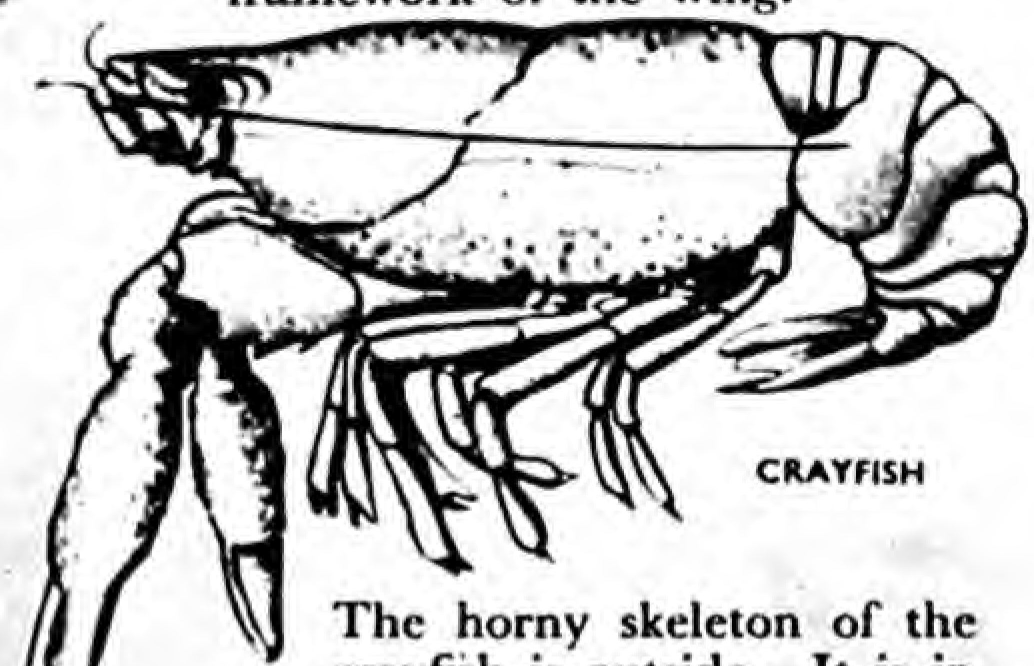
The long bones of vertebrates are jointed to one another. This makes movement possible.

Bones of fingers and toes are long. They carry the webbing of the feet.

The snail carries his skeleton on the outside, it is formed of lime carbonate.



The bones of the forearm and fore finger have developed to form the framework of the wing.

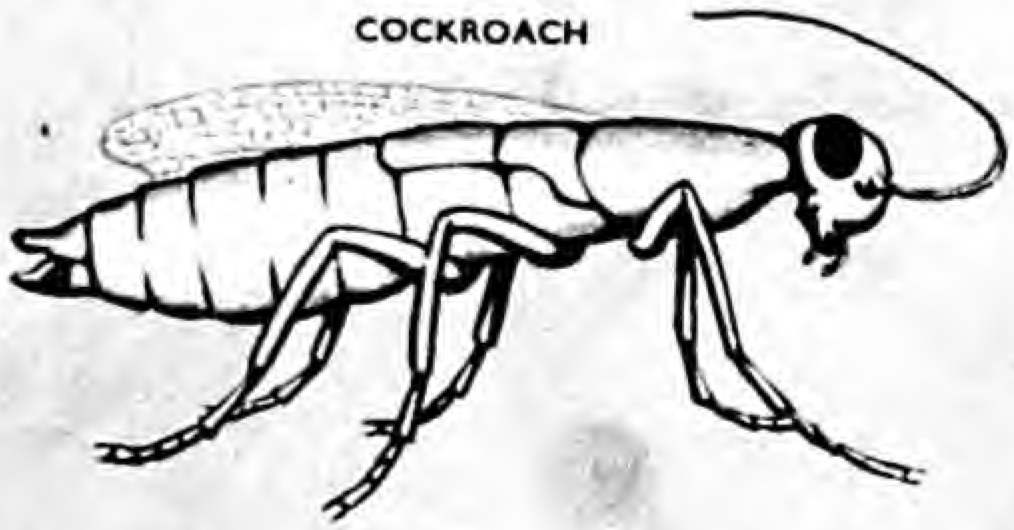


The horny skeleton of the crayfish is outside. It is in segments hinged together.

The backbone of the fish is divided into many small joints to allow the body to bend easily.

The worm has no hard skeleton either outside or inside.

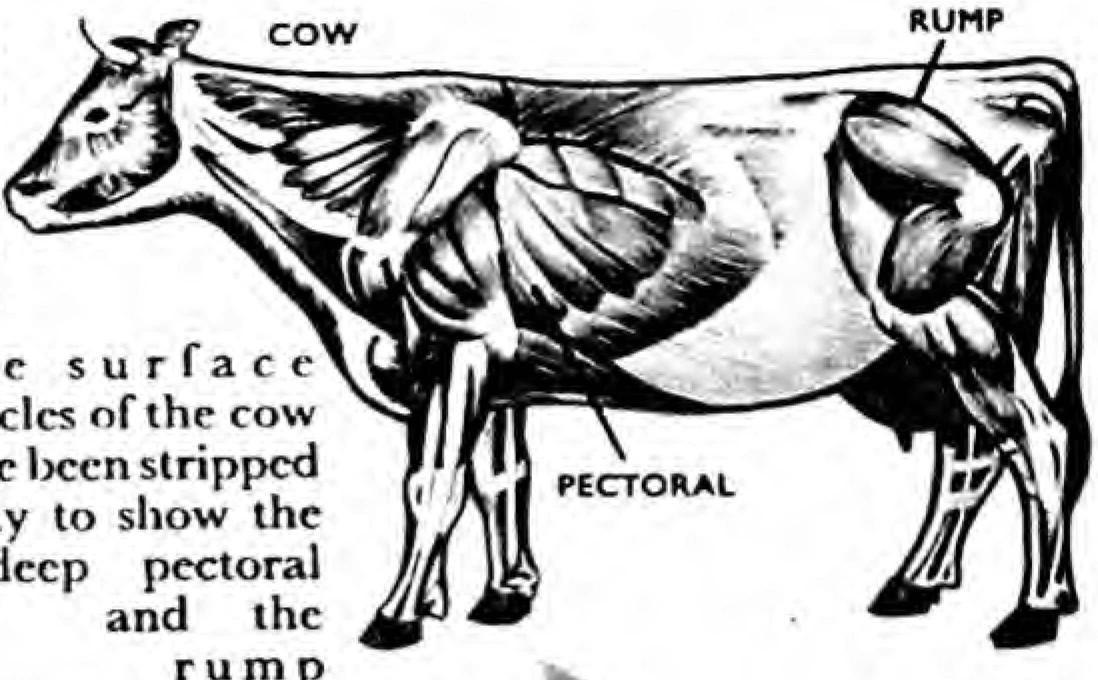
In the cat the spine is continued into a tail as in most mammals.



The cockroach also has a horny exoskeleton. The segments are hinged in the same way as they are in the crayfish.

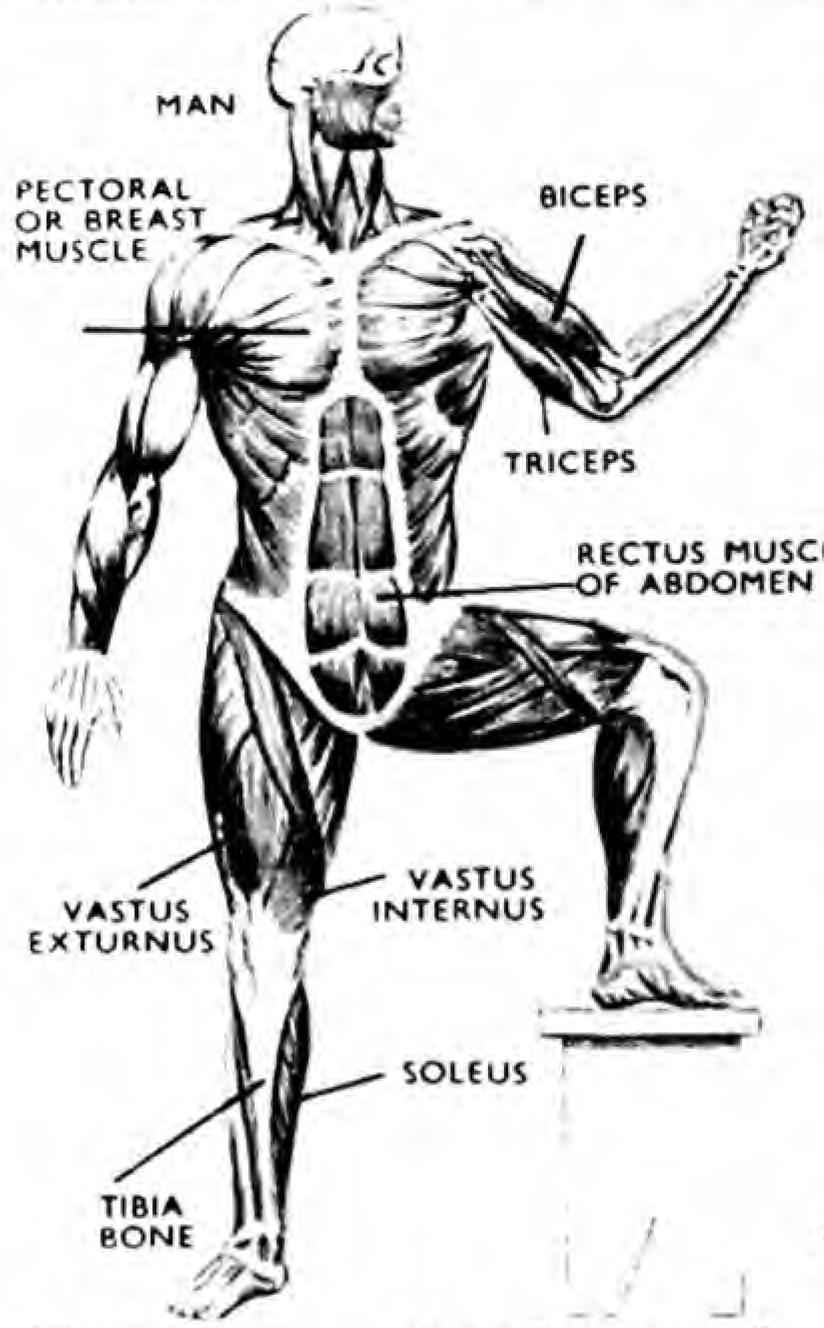
Muscles

The meat of an animal is made up of muscles attached at each end to bones over which they form a covering. By contracting muscles move the bones and limbs are worked. Invertebrate creatures have an outer skeleton and have all their muscles inside this. The worm has no hard skeleton but still moves by muscular contraction. A similar method is used by the snail.

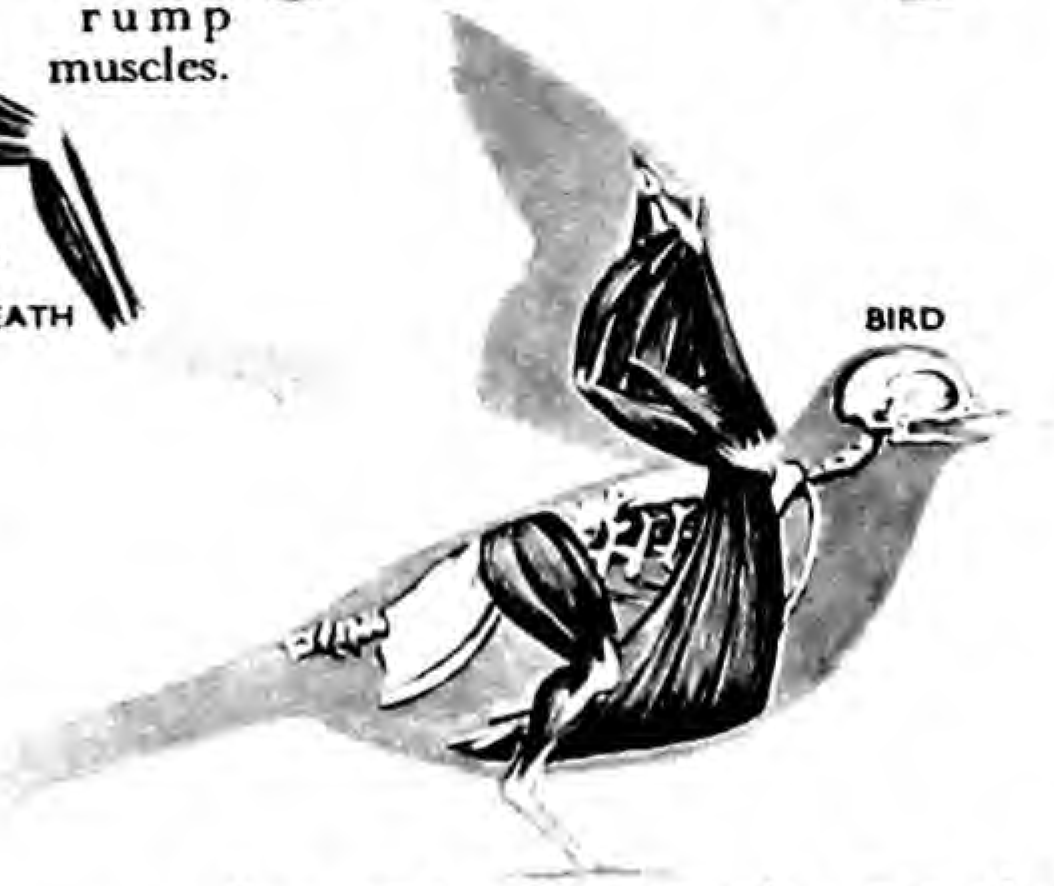


The surface muscles of the cow have been stripped away to show the deep pectoral and the rump muscles.

This is a ventral aspect of frog showing the powerful muscles in the hind legs.



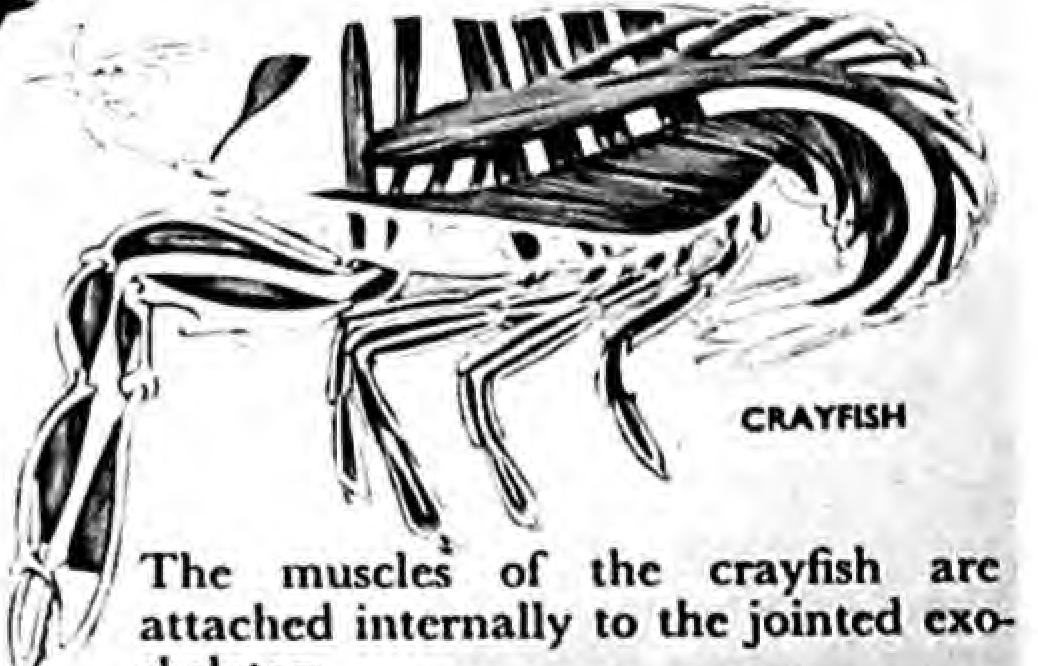
The surface muscles of man's left arm are stripped away to show biceps and triceps.



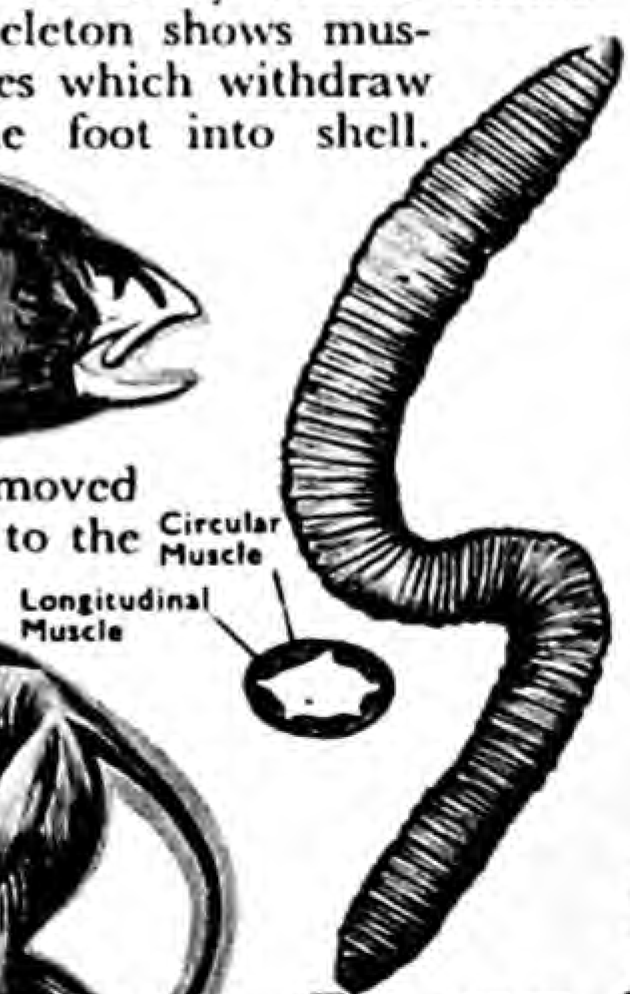
Leg and wing muscles are the strongest in a bird. The wing muscle is what we call the 'breast' in chicken.

A cut-away of the snail's skeleton shows muscles which withdraw the foot into shell.

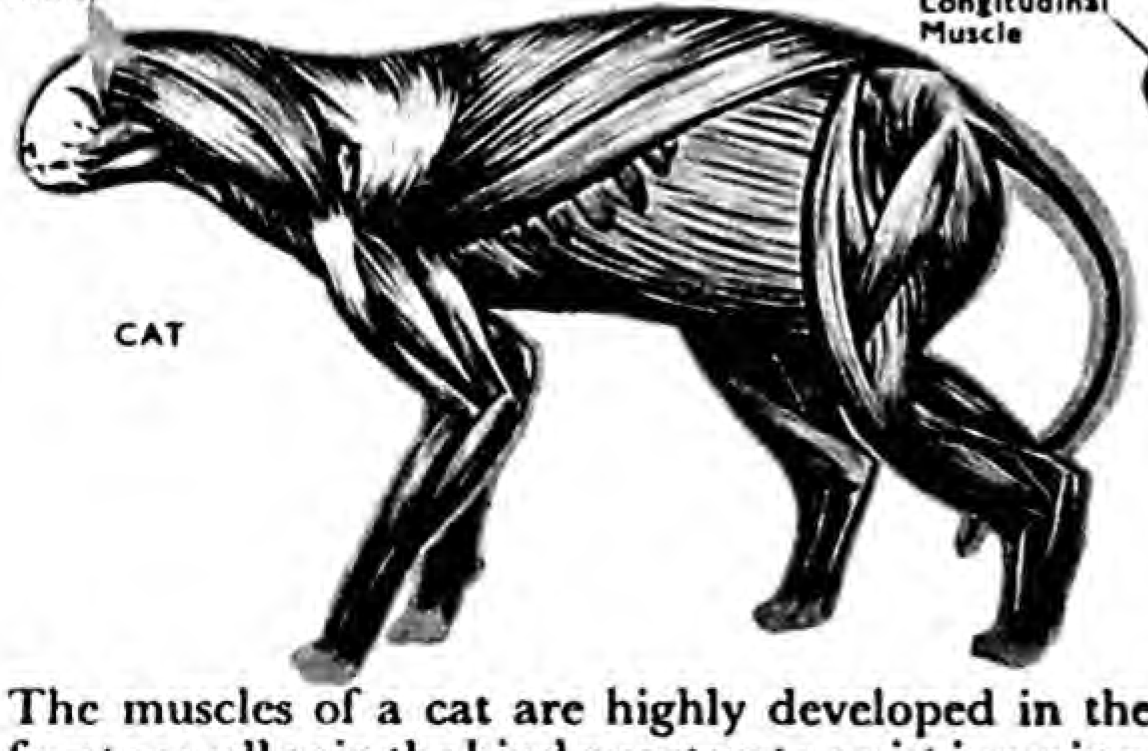
The 'flakes' are the muscles. The tail is moved by contractions passing from one pack to the next.



The muscles of the crayfish are attached internally to the jointed exoskeleton.

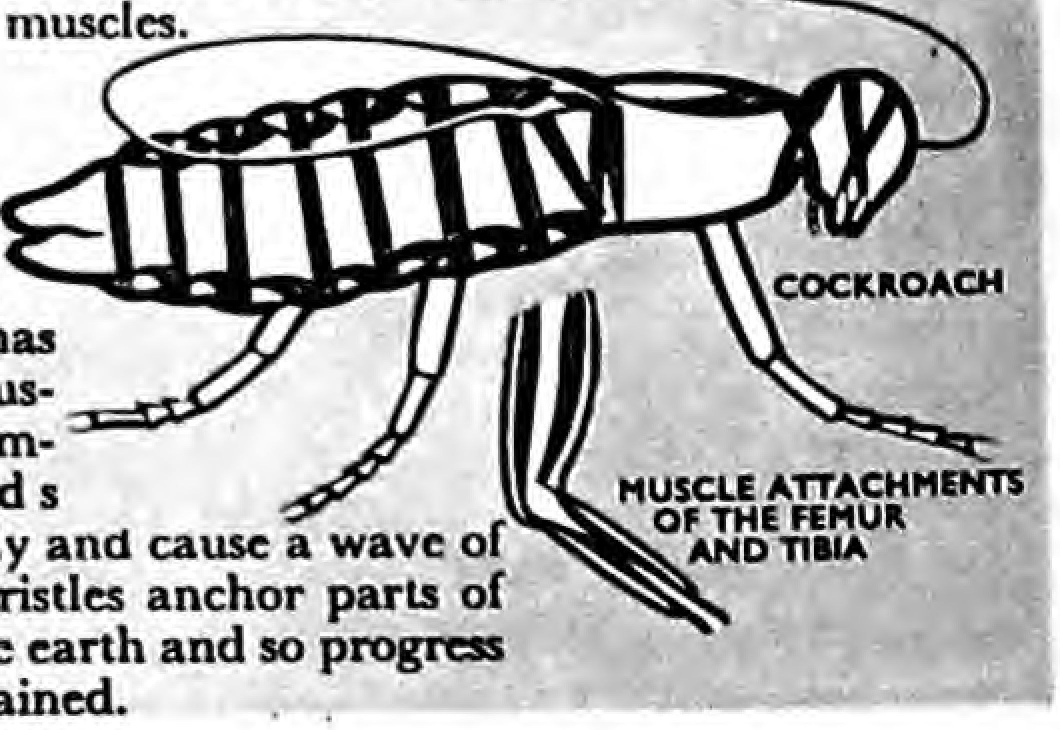


The worm has two sets of muscles. They compress fluids within the body and cause a wave of contraction. Bristles anchor parts of the body to the earth and so progress forward is obtained.



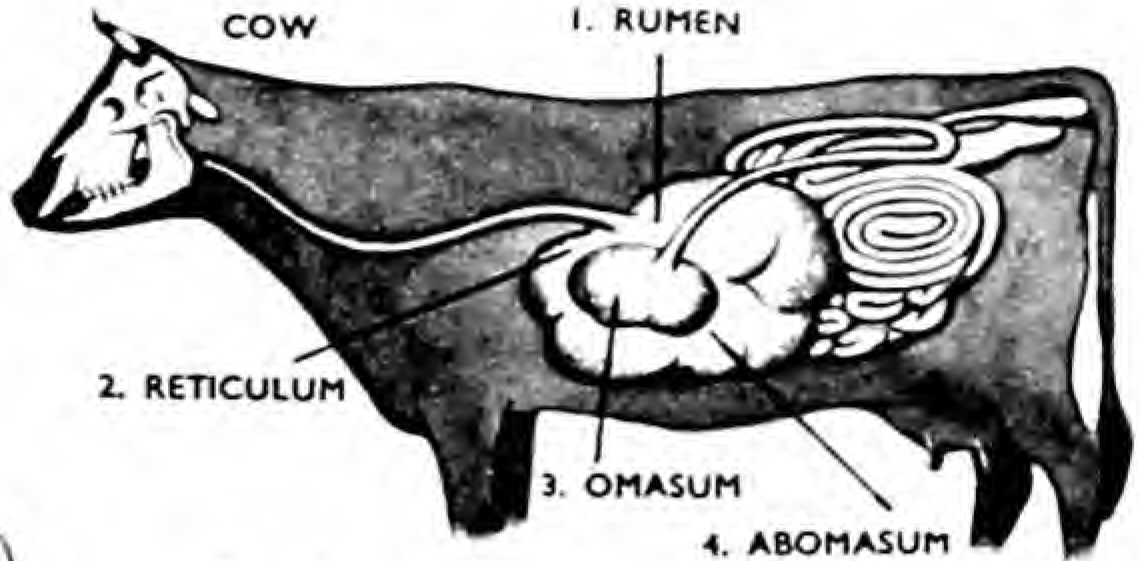
The muscles of a cat are highly developed in the front as well as in the hind quarters to assist jumping.

The cockroach, below, also has internal muscles.

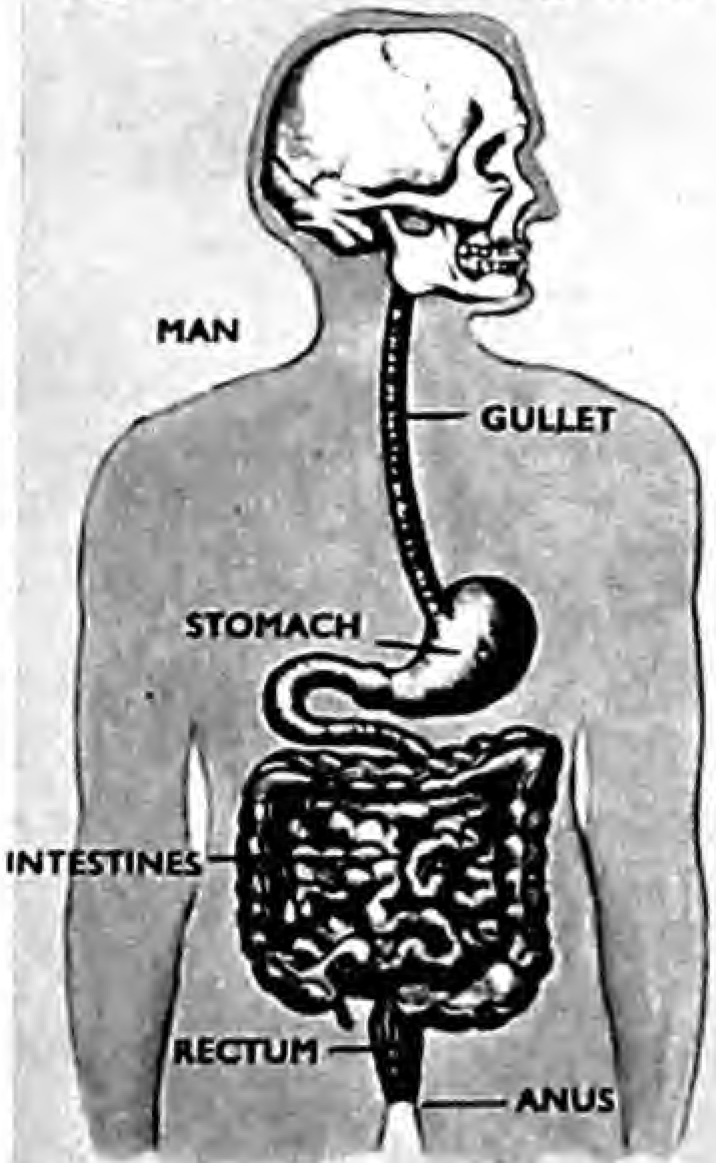


The Digestion

When we masticate and swallow, food passes down to the stomach and intestines where part of it is extracted to permit growth and to provide energy. Herbivores have a more complicated system than other animals because of the large content of indigestible cellulose in their food.



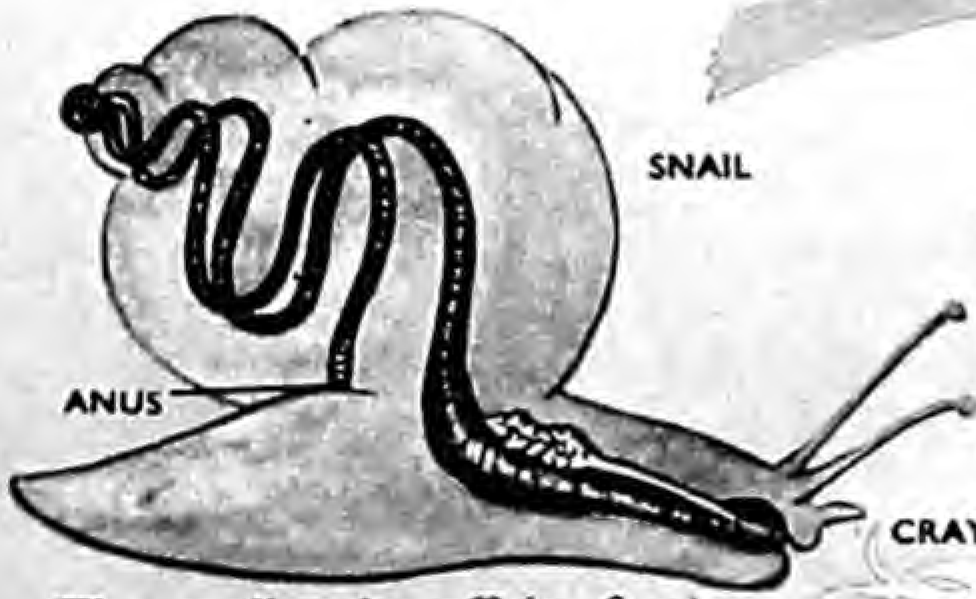
Cow has four stomachs. Grass is swallowed into the first without chewing. Later it is returned to the mouth, chewed and passed in turn to the remaining three stomachs where digestion continues. The intestine is very long.



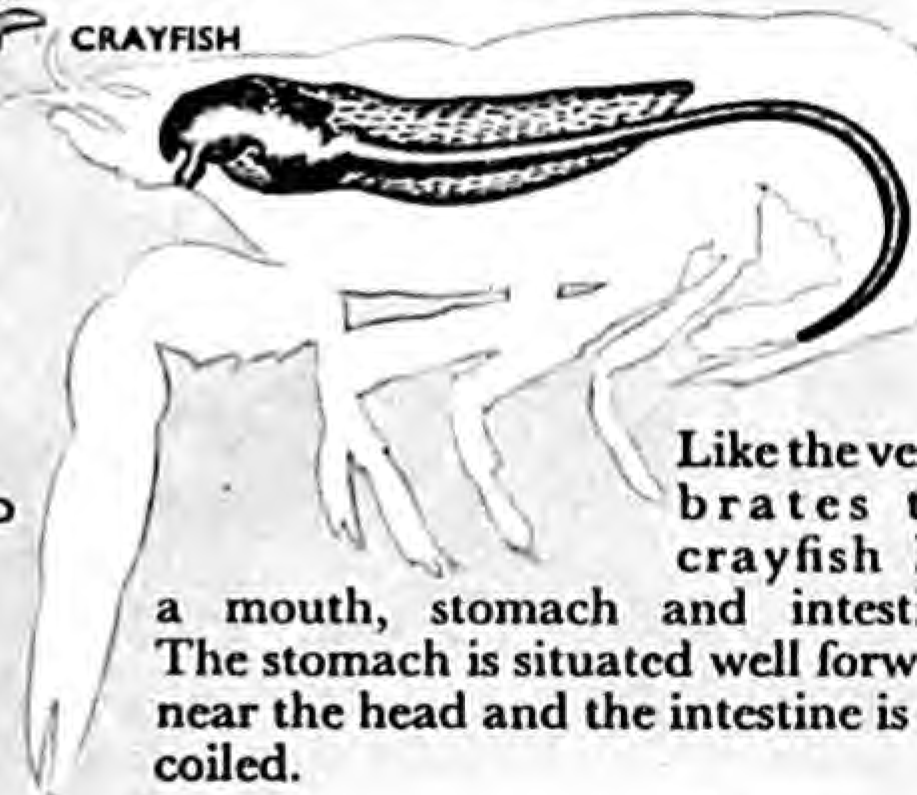
The alimentary canal is a tube which starts in the mouth, passes by way of gullet, stomach and intestine to the anus.

The frog has a very short gullet and, because he is a meat eater, a short intestine as well.

The bird has a crop in addition to the gullet, stomach and intestine. The stomach (or gizzard) is a muscular bag in which stones grind up the hard dry food.



The snail rubs off its food with its file-like tongue. The intestine is long and coiled.

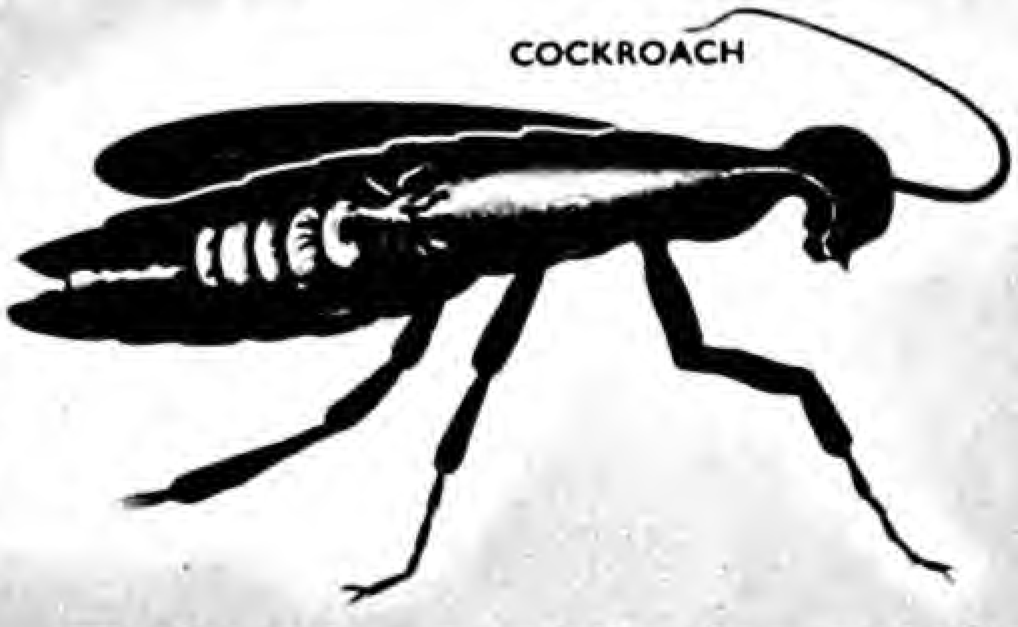


Like the vertebrates the crayfish has a mouth, stomach and intestine. The stomach is situated well forward near the head and the intestine is not coiled.

The food passes through mouth, stomach and intestine; this is very short as the water creatures which make up its food are easily digested.

The worm has a gizzard Like a bird's. It is used for grinding up the food in the soil which the worm swallows.

From the gullet and stomach the food passes through the intestine. In the cat this is short as the animal is a meat eater. Meat digests easily.

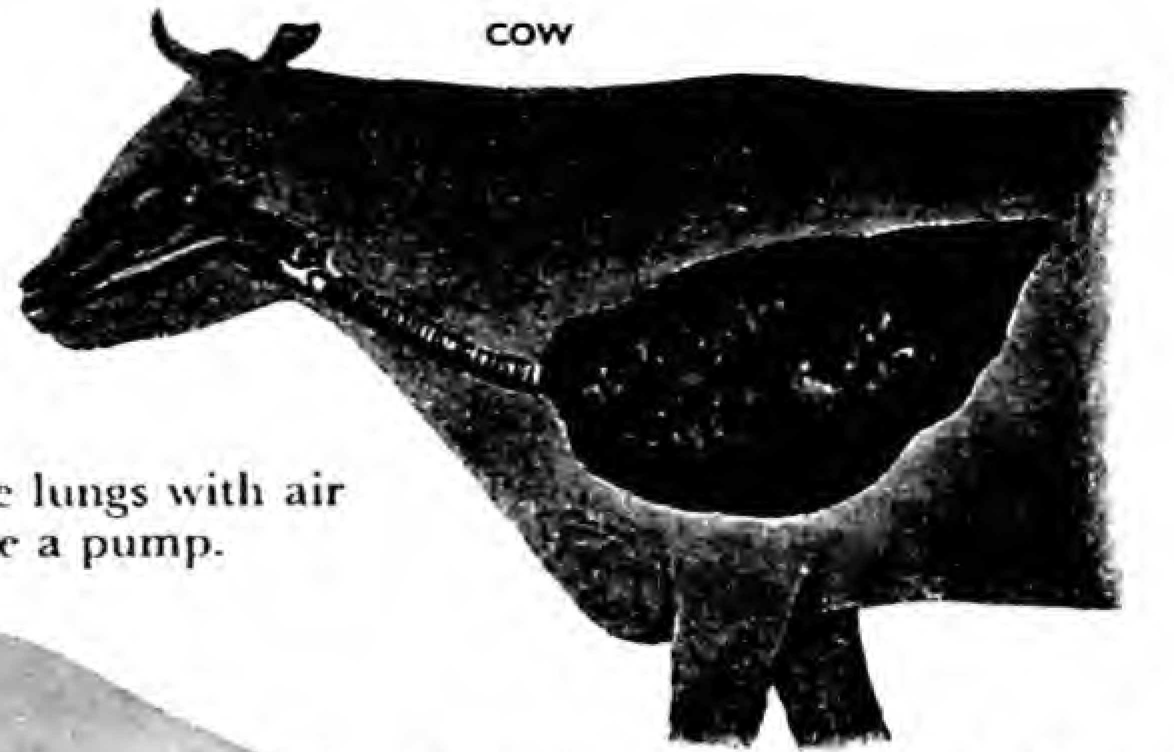


The insects' organs of digestion are similar to those of the crayfish, but in a cockroach there are a crop and gizzard.

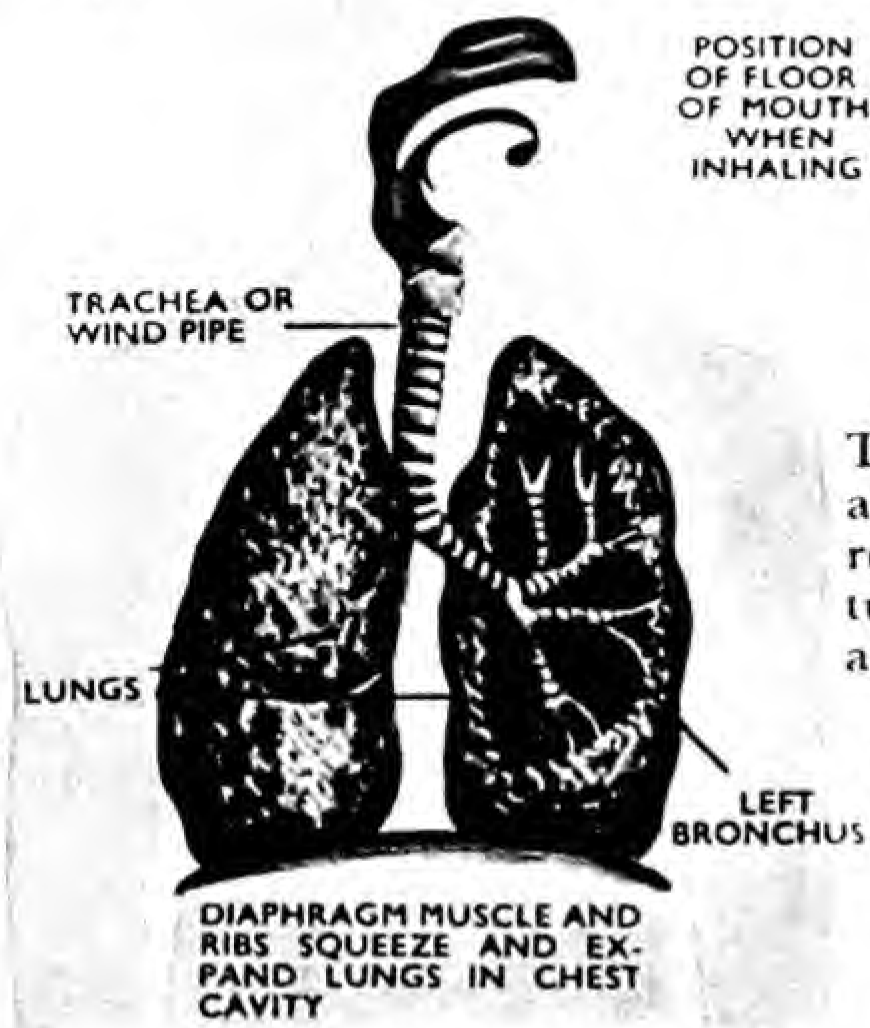
CHARLES GREEN

Respiration

When we inhale the ribs move and enlarge the chest. As a result air enters the lungs whose walls contain a rich network of blood vessels in which the blood is aerated. Not all creatures have lungs. Some, like the fish use gills, and others, like insects, obtain oxygen by direct openings through the body wall.



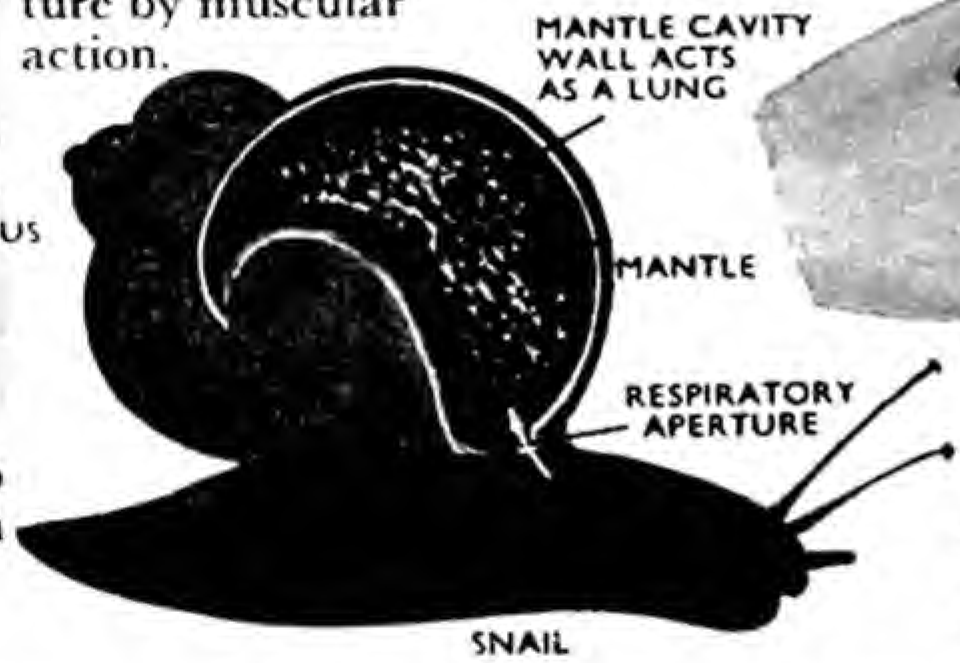
The respiratory system of the cow is like man's but, as in cat, the trachea and lungs lie horizontally.

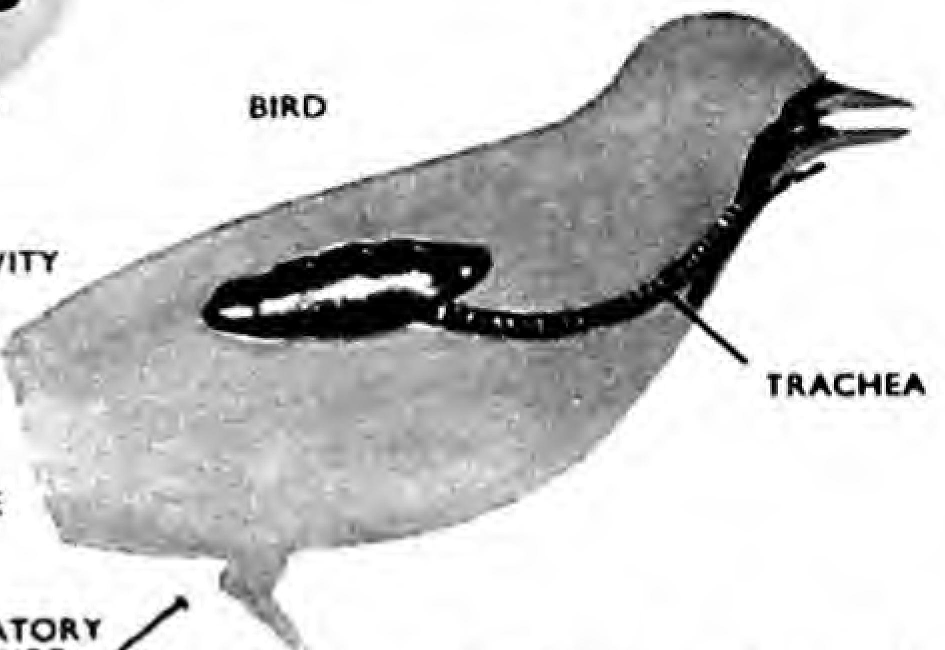


In man the left lung is cut away to show the bronchial tubes. Beneath the lungs lies the diaphragm.

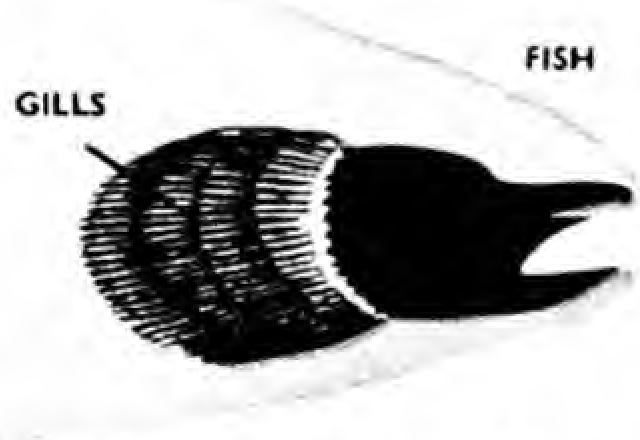
Frog has no ribs and to fill the lungs with air the floor of the mouth acts like a pump.

The snail obtains air through the respiratory aperture by muscular action.





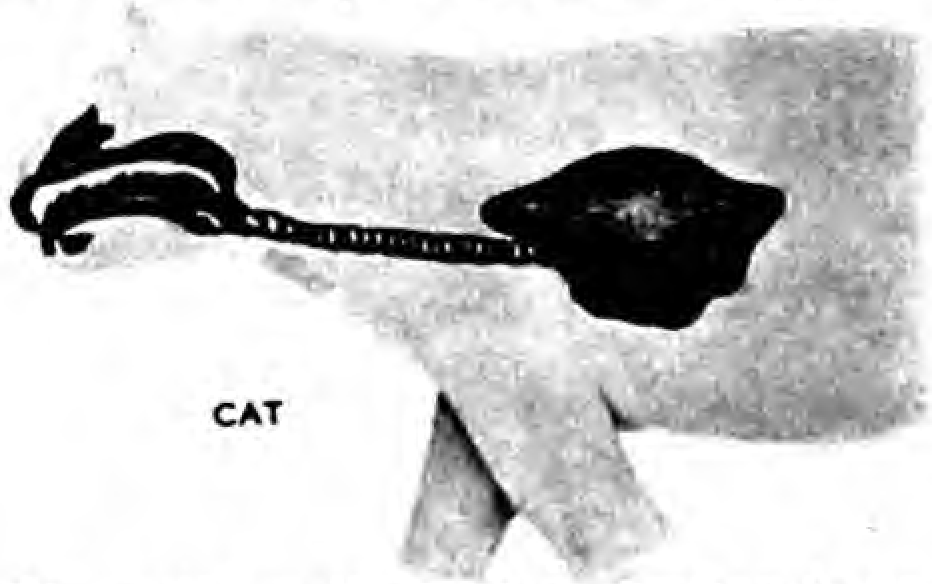
In flight the bird needs much oxygen. Air is pumped to and fro through the lung into sacs within the bones.



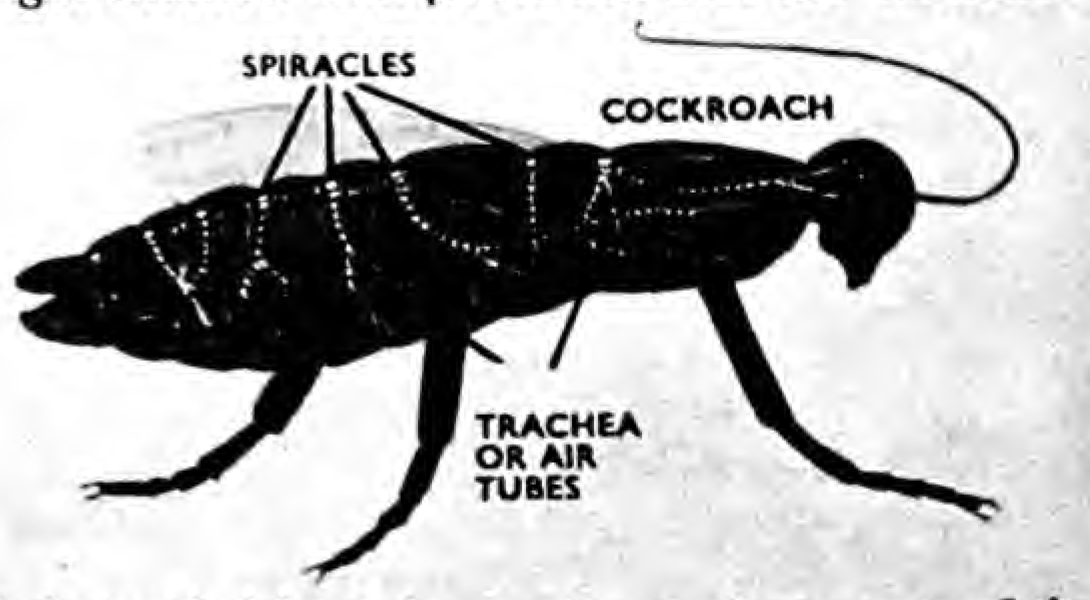
Fish have no lungs. Dissolved oxygen is extracted from water which enters the mouth and passes out over the gills.

Oxygen passes directly into the capillaries in the wet skin.

The gill rakers extract dissolved oxygen from the water. This enters the gill chamber and passes out over the 'feathers'.



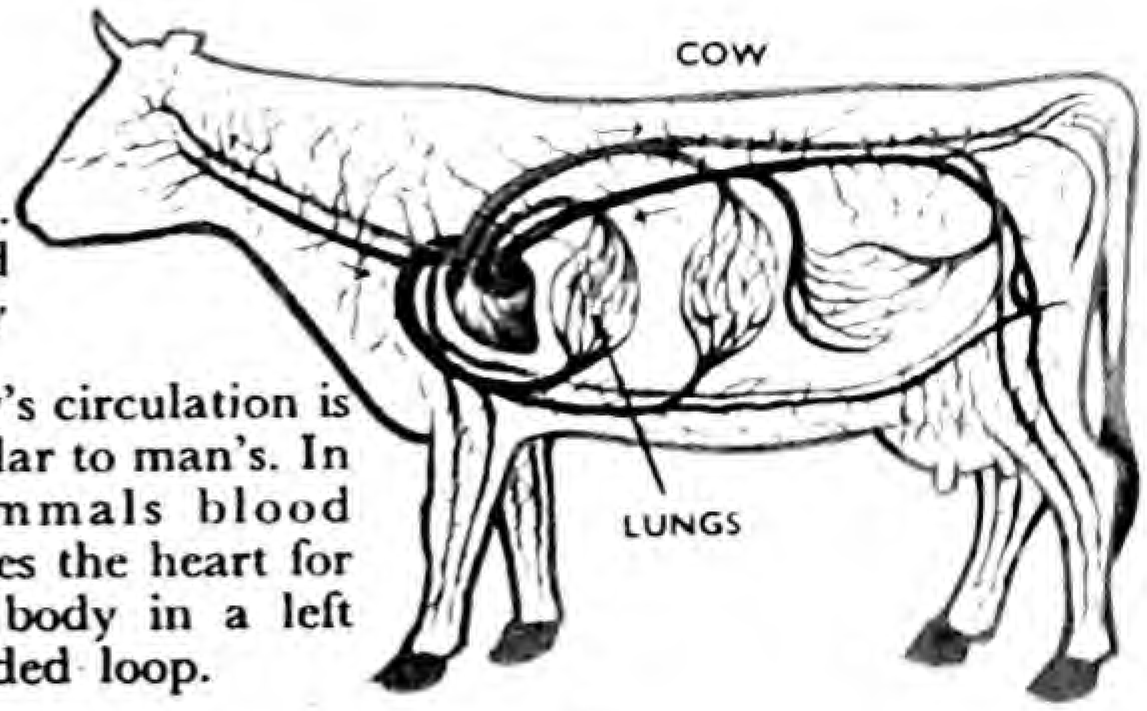
The cat's method of respiration is very similar to man's but the trachea and lungs lie in a horizontal position.



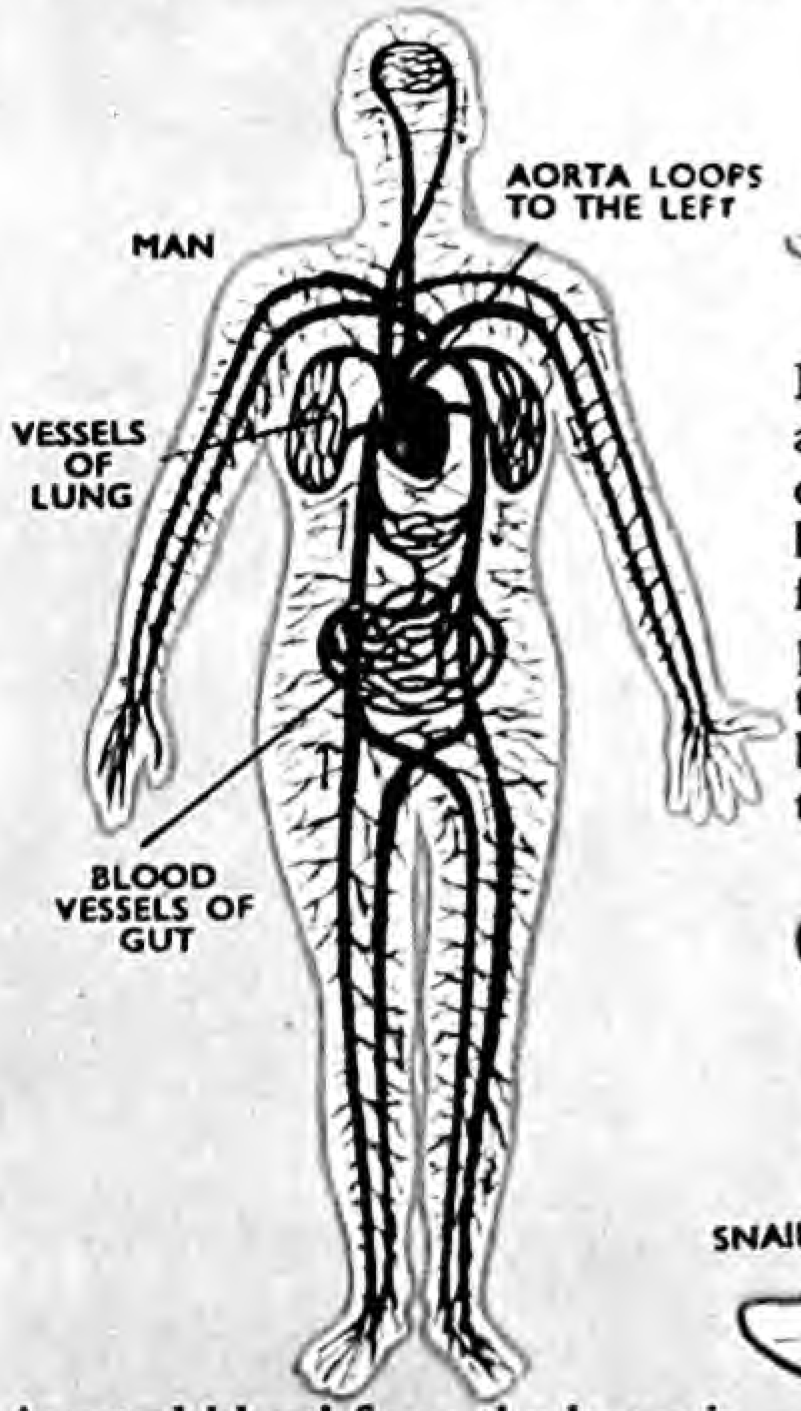
Air is carried by tubes to the various parts of the body. It is pumped in and out by the body's movements.

The Blood Stream

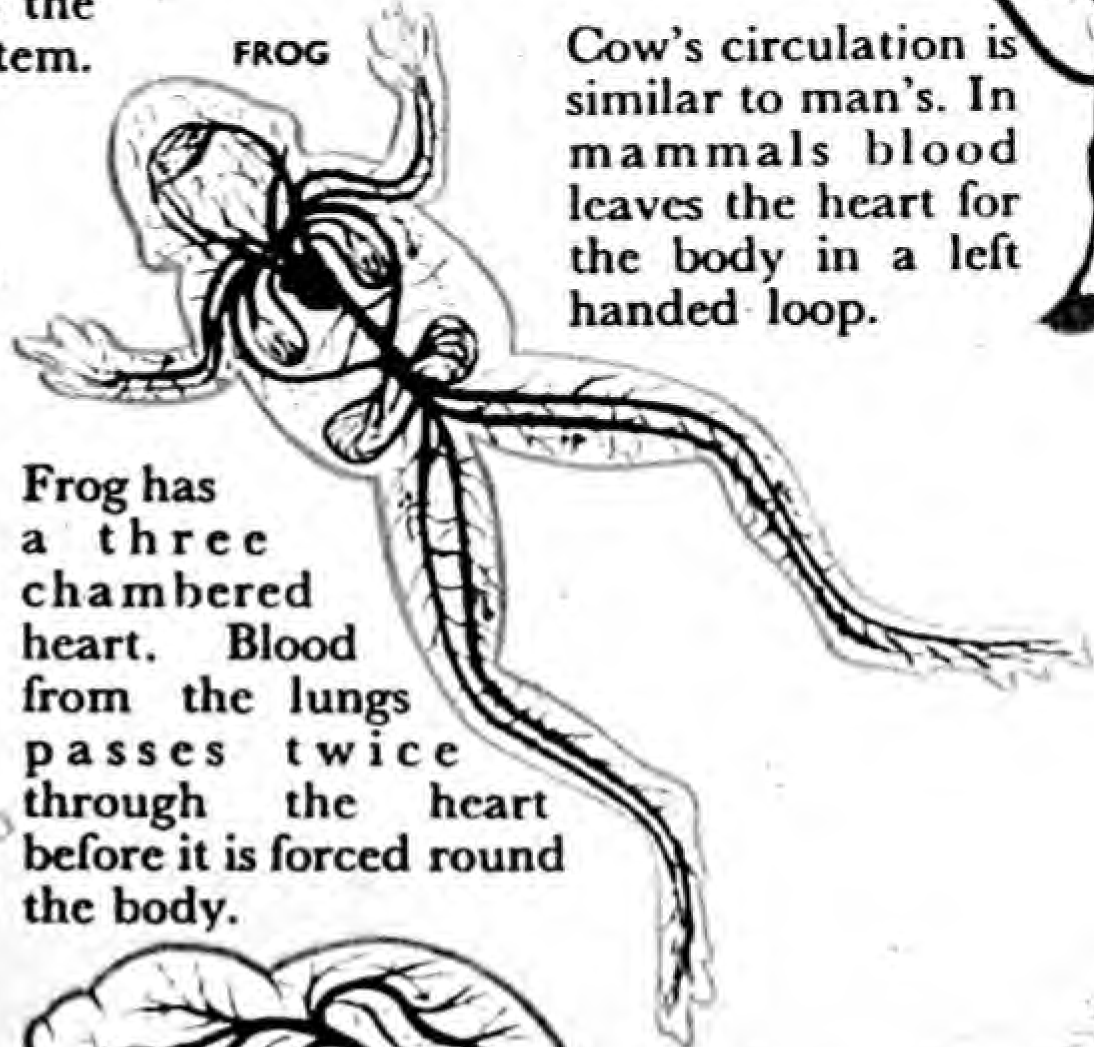
The heart is a pump which forces blood through the body. Some creatures, like insects, have no well defined heart and blood vessels. The blood simply moves about within the body spaces. A surprising creature is the worm, he has five hearts to his system.



Cow's circulation is similar to man's. In mammals blood leaves the heart for the body in a left handed loop.

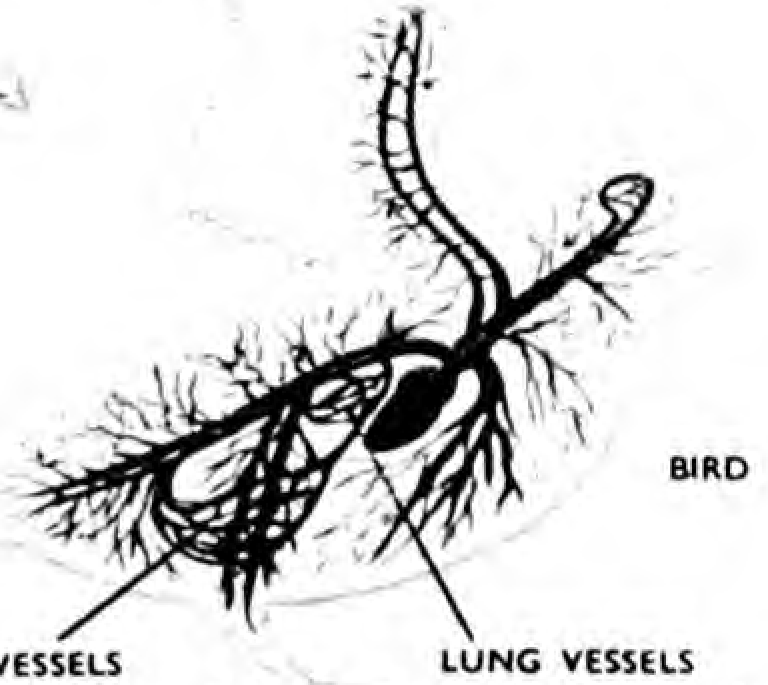


Aerated blood from the lungs is pumped round the body by the four chambered heart.

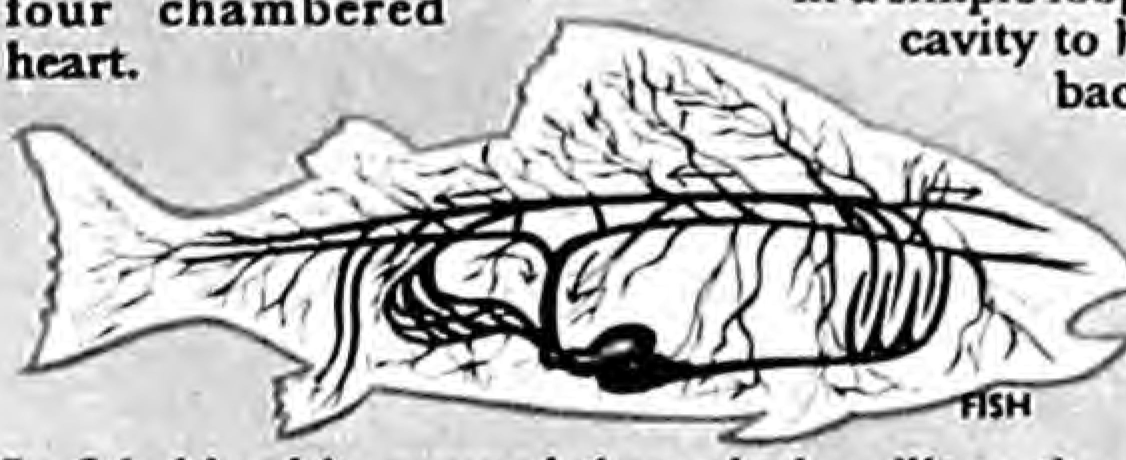


Frog has a three chambered heart. Blood from the lungs passes twice through the heart before it is forced round the body.

The heart circulates blood in a simple loop from mantle cavity to body and back.

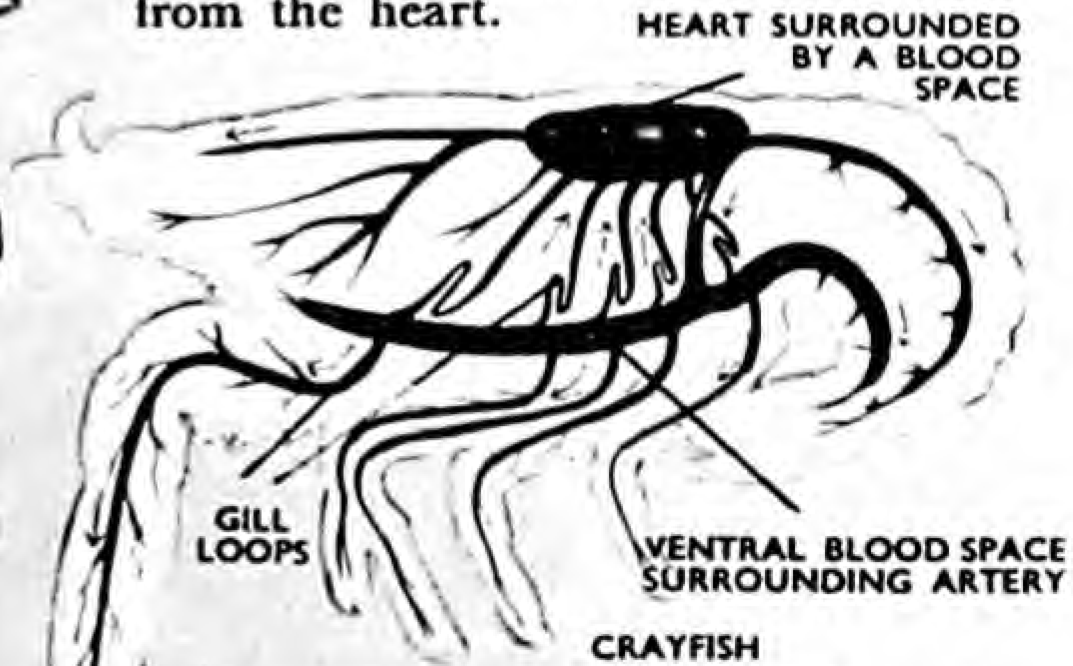


Bird's circulation is like that of the mammals (man, cow, cat), but proceeds in a right handed loop to the body from the heart.

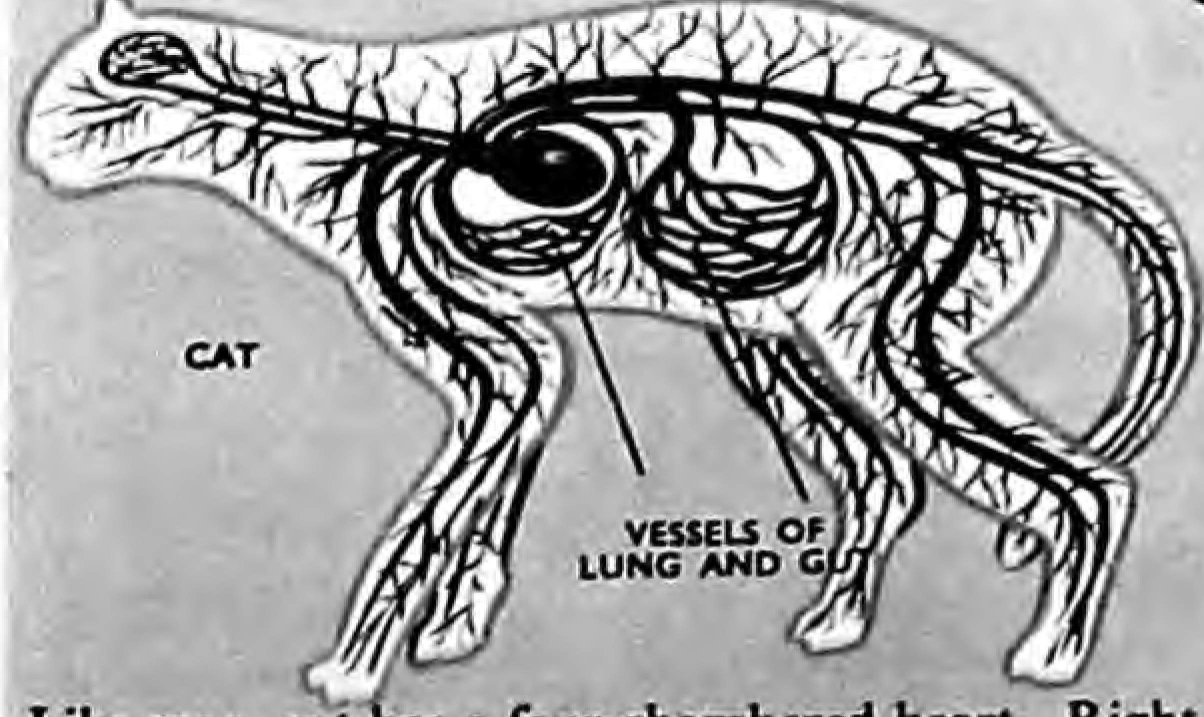


In fish blood is pumped through the gills to the body by a simple heart.

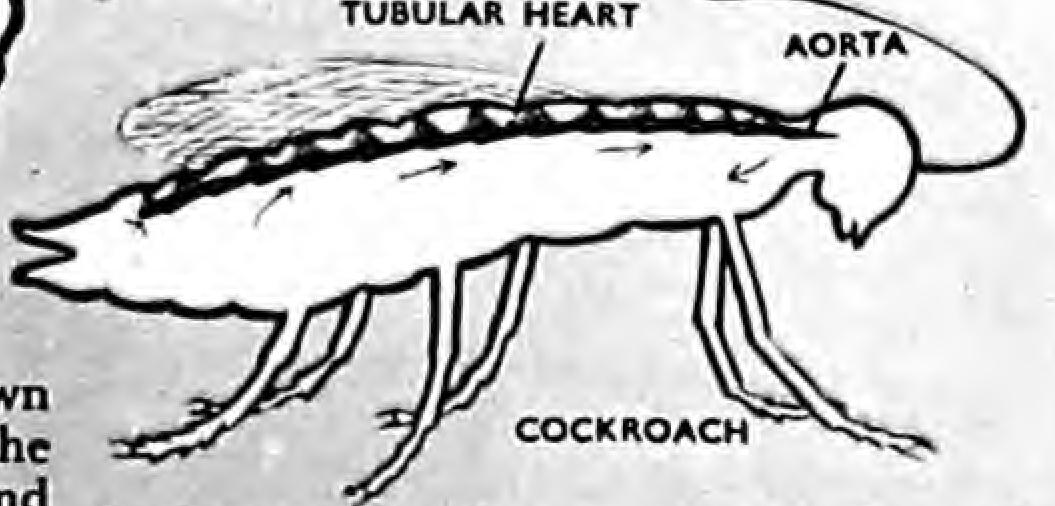
Blood is drawn forward in the upper vessel and pumped by five ring shaped hearts into the lower vessel.



A simple heart pumps blood through vessels to the body. It returns through sac like spaces.



Like man, cat has a four chambered heart. Right ventricle pumps to lung, left to body.

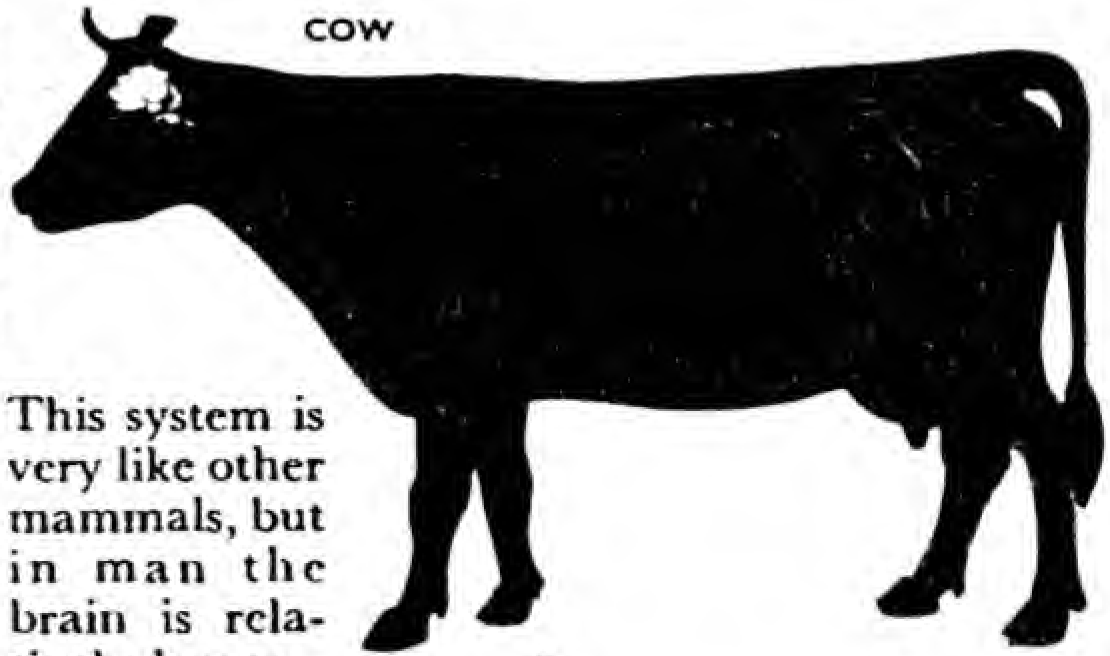


In insects the heart extends along the back. It is open ended and forces blood through the body space.

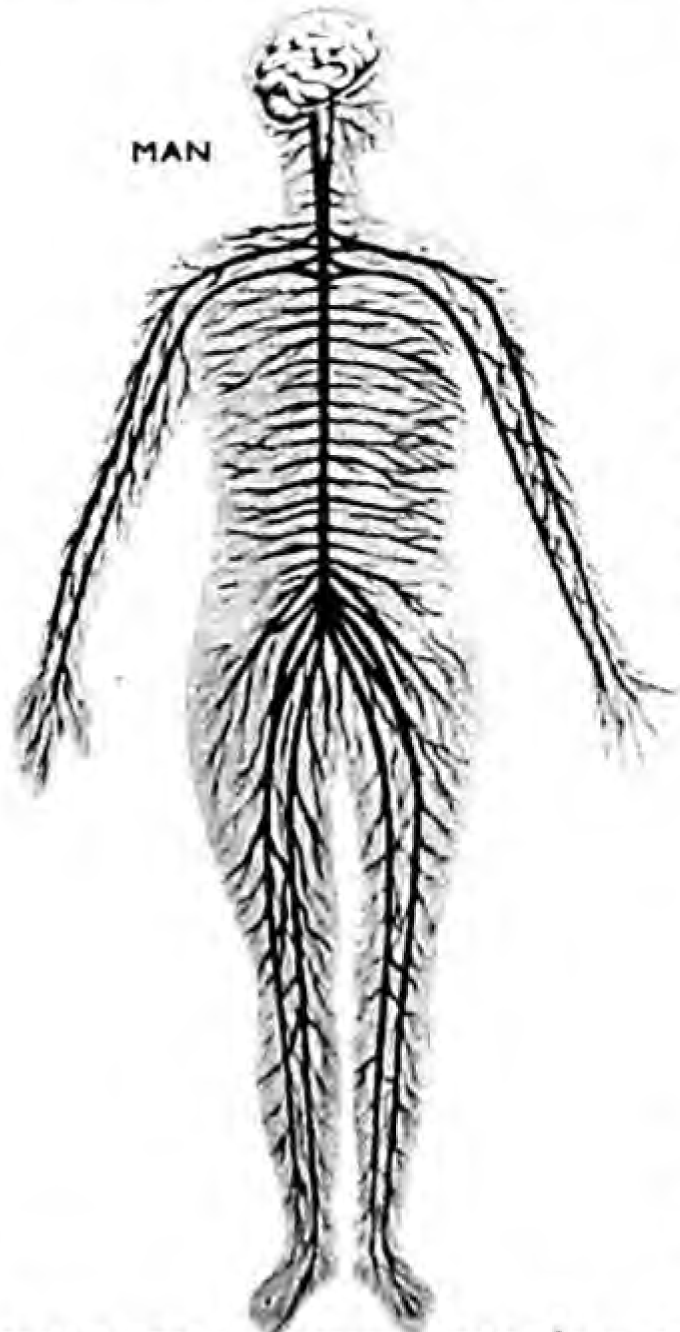
CHARLES GREEN

The Nerves

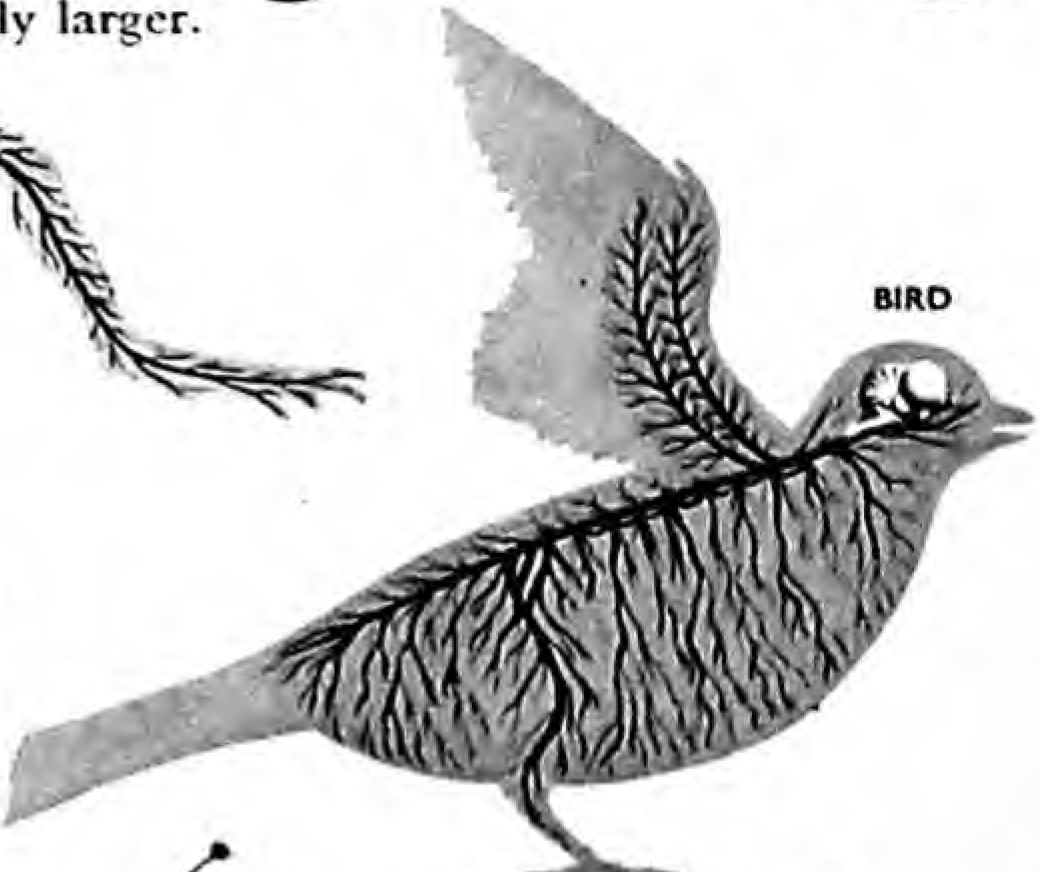
The nervous system of the vertebrate is one of the most complicated parts of the body. It controls all the other systems of the body. The brain is the main nerve centre and injury to any part of it can cause disability or death. Some creatures have no definite brain but instead have a nerve ring developed at the front end.



This system is very like other mammals, but in man the brain is relatively larger.



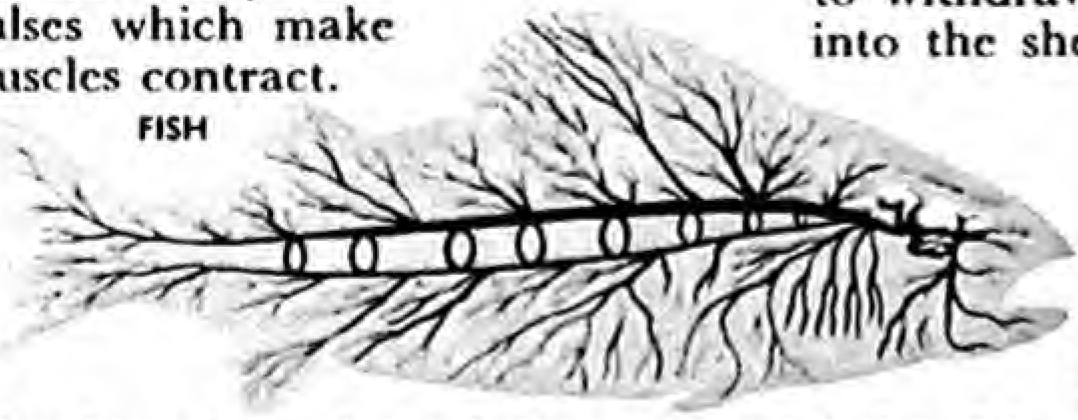
The brain, which is really very small, is here shown exaggerated.



As in all vertebrates the main nerve runs the length of the back. Its front end is the brain.

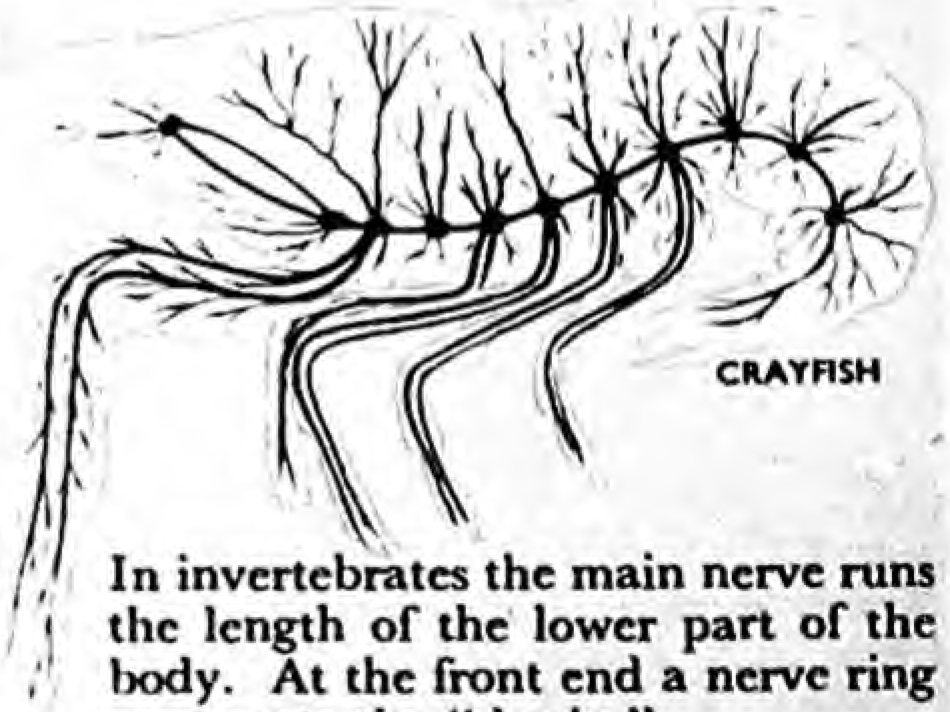
Some nerves convey impulses to the spinal cord and the brain. Others carry impulses which make muscles contract.

The main nerves are related to eating and to withdrawing into the shell.

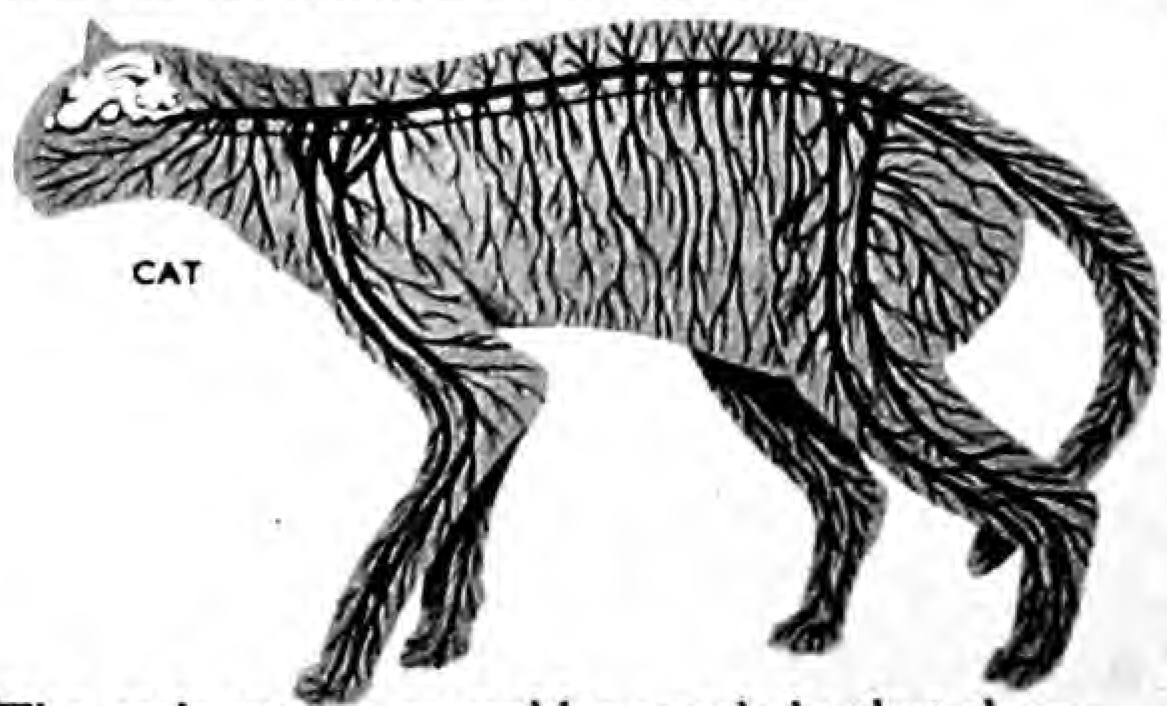


The important lateral line nerve of the fish receives vibrations from the water.

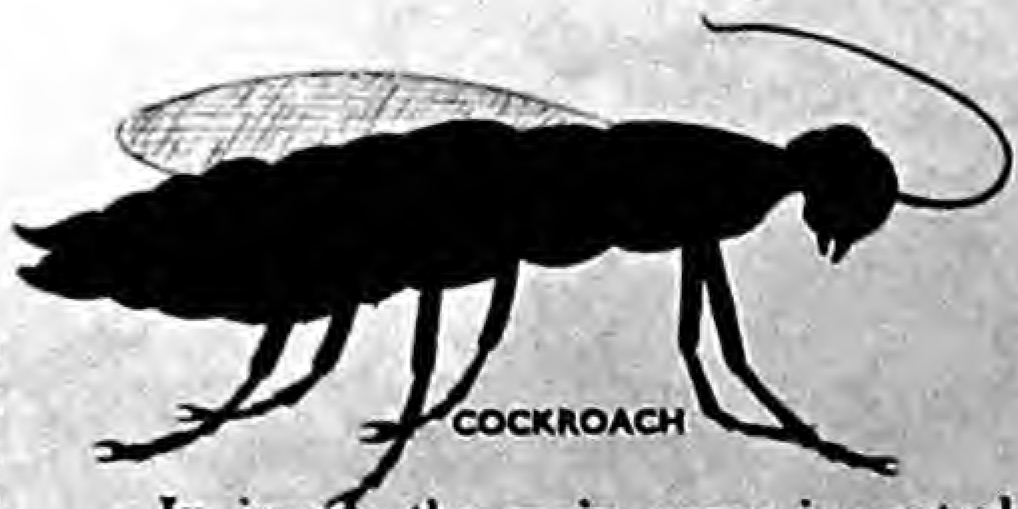
As in crayfish the main nerve is ventral. Branch nerves extend throughout the skin.



In invertebrates the main nerve runs the length of the lower part of the body. At the front end a nerve ring represents the " brain ".



The cat's system resembles man's in that there are both sensory and motor nerves.



In insects the main nerve is ventral. The " brain " is a ring of nerve about the front end of the gut.

CHARLES GREEN

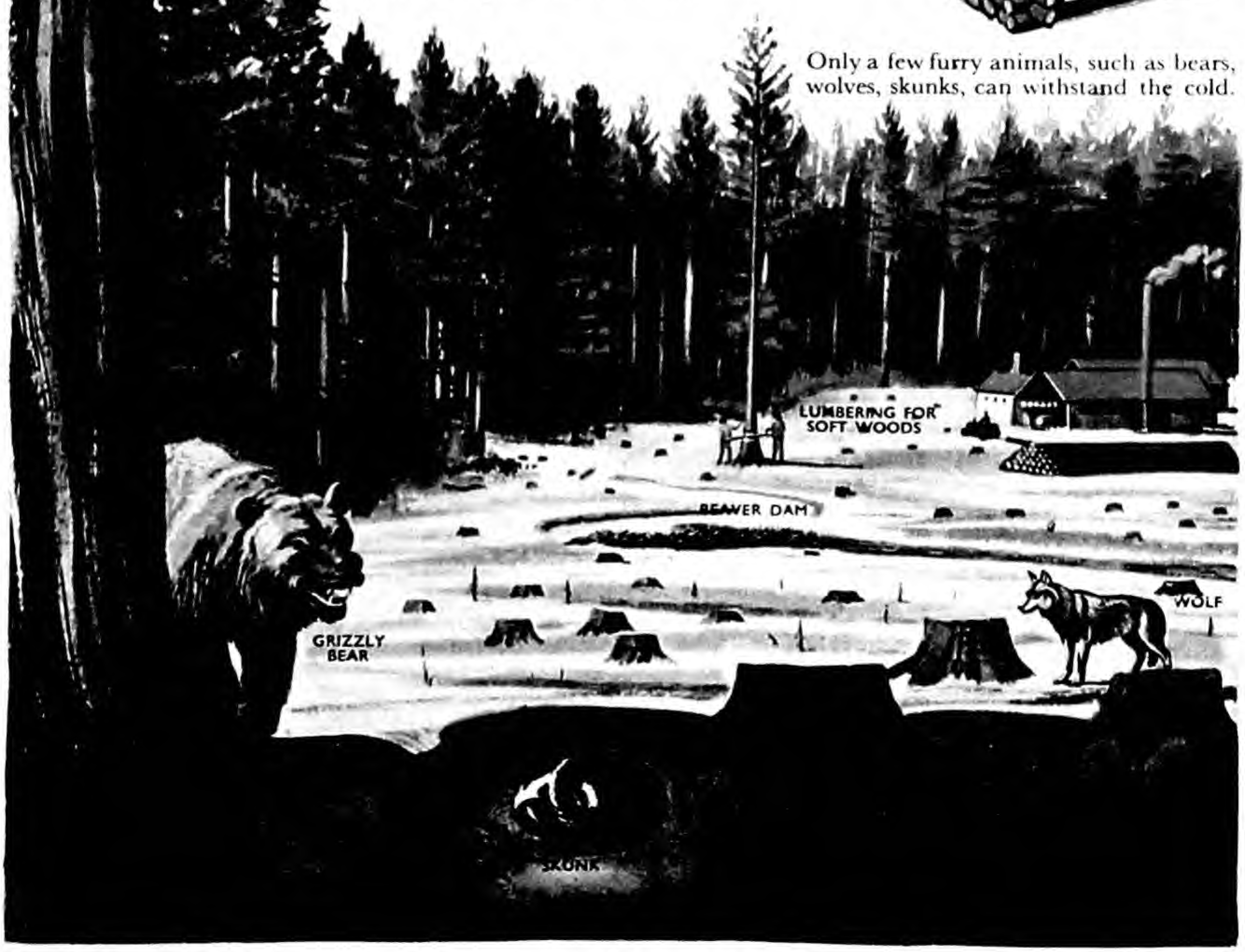
LIFE IN COOL LANDS

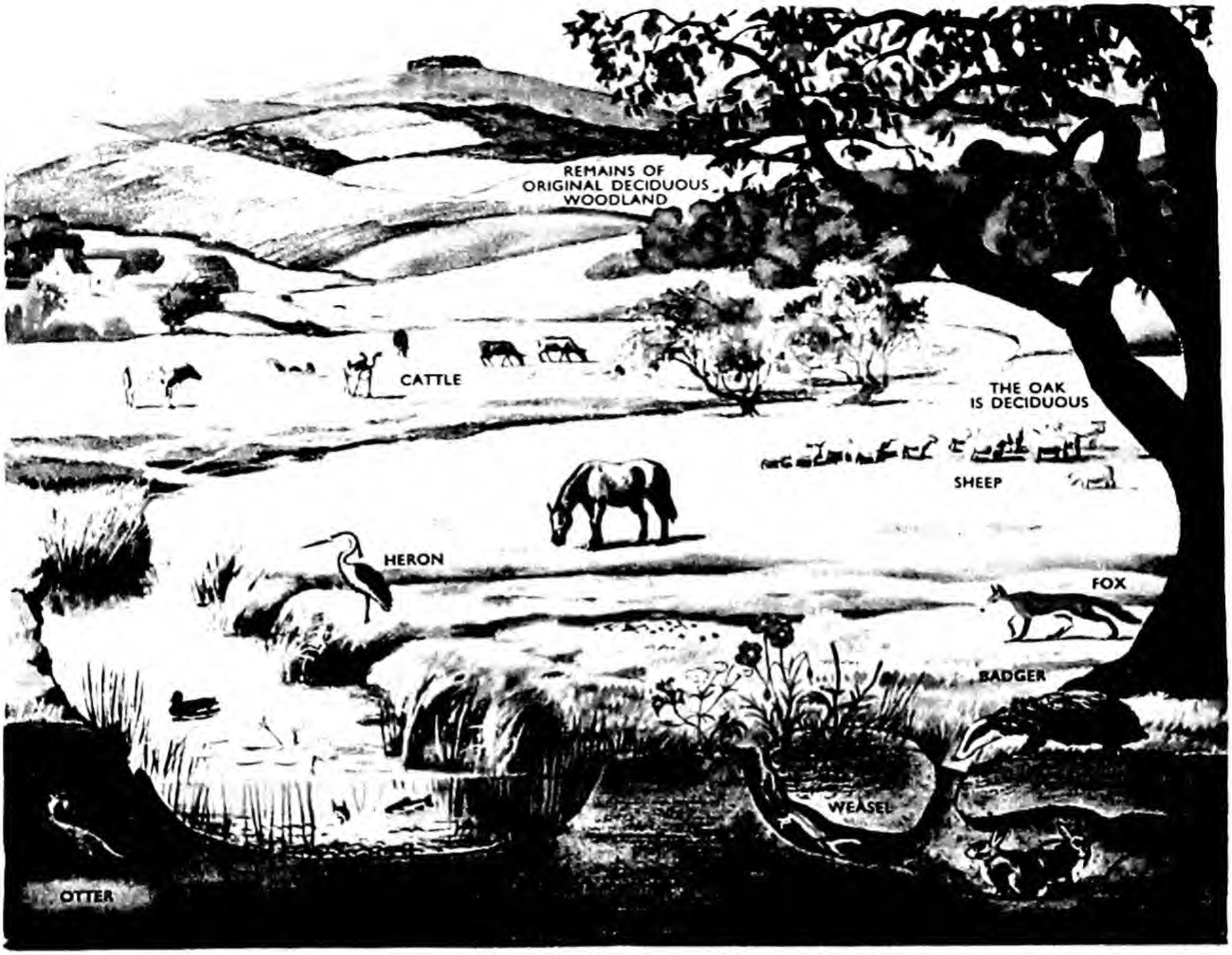
Coniferous Type

Because of its distance from the sea this heavily forested region has hot summers and very cold winters.

With so much wood available, houses are often made of logs. The cleared land is used for farming.

Only a few furry animals, such as bears, wolves, skunks, can withstand the cold.



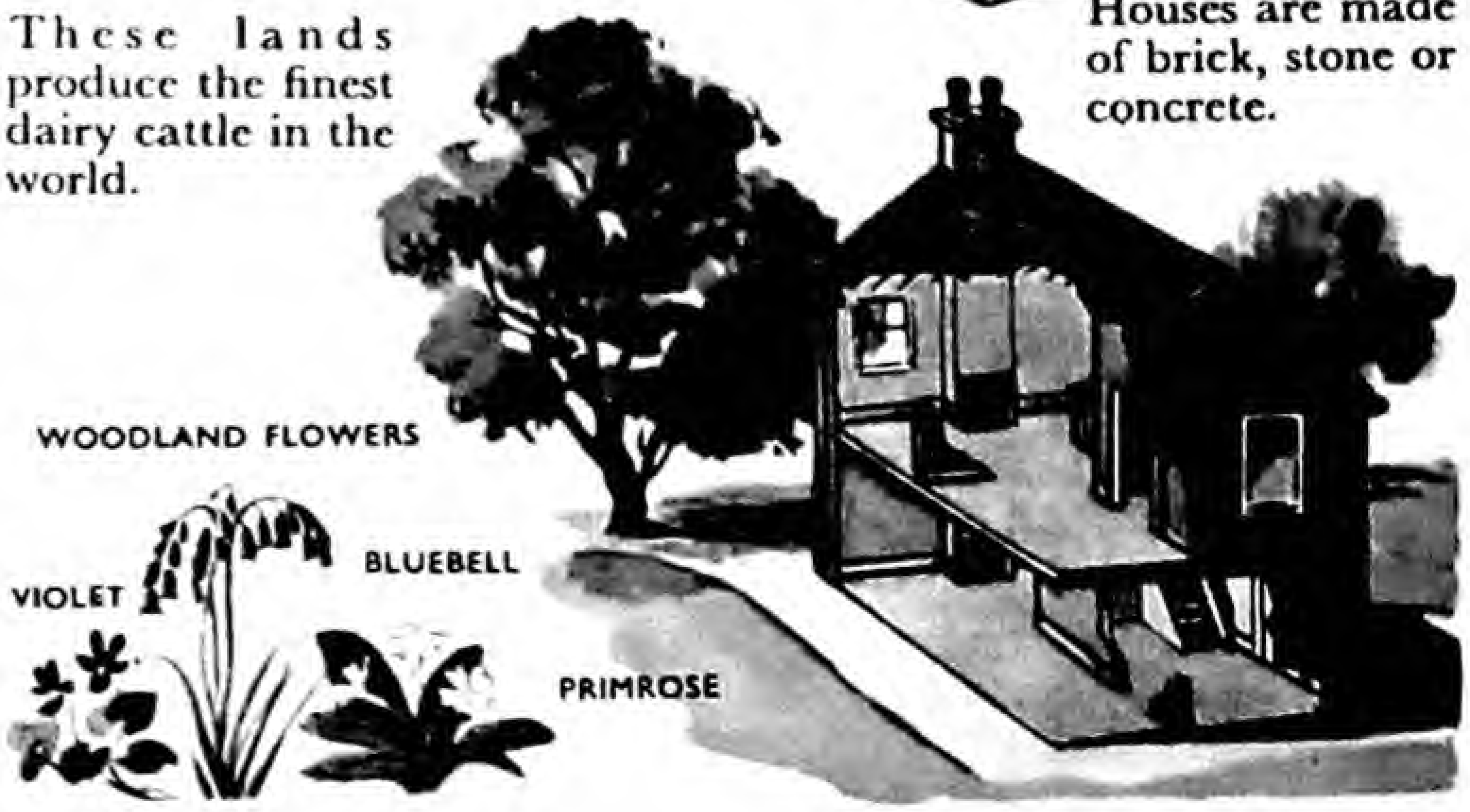


British Type

The mild damp climate of these areas is brought about by the surrounding sea (*see page* 182). Once heavily wooded, the land in Britain has now been almost cleared for farming. Cattle and sheep prosper in the always-green meadows.

Houses are made of brick, stone or concrete.

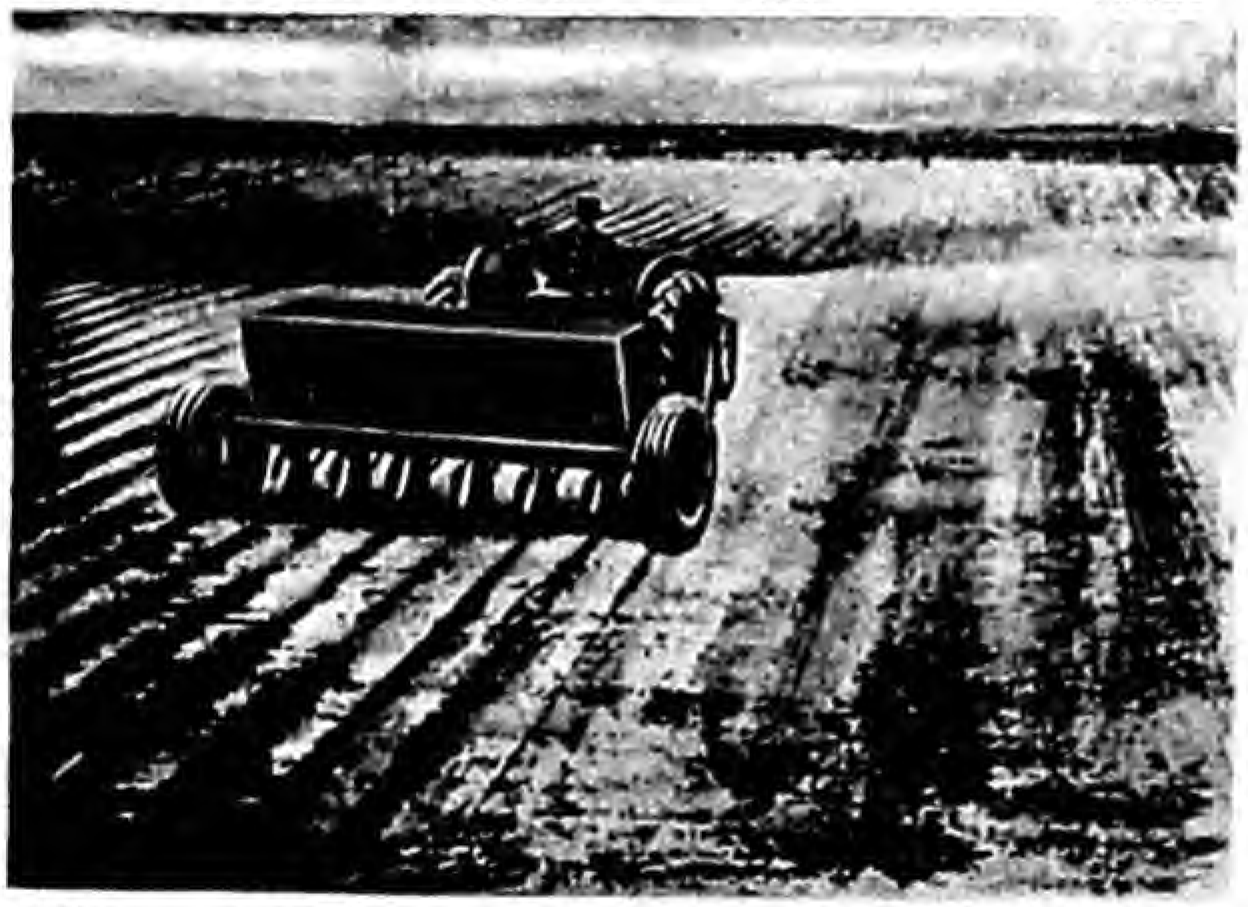
These lands produce the finest dairy cattle in the world.



Dry Cool

This region has bitterly cold winters and long mild summers ; in Canada the cold is brought by cyclones, the summer weather by easterly winds from the sea. The mild summers are suitable for the growing of cereals, the quick-ripening crops in the vast plains being harvested by machines which sweep across the country.

TYPES OF CEREAL

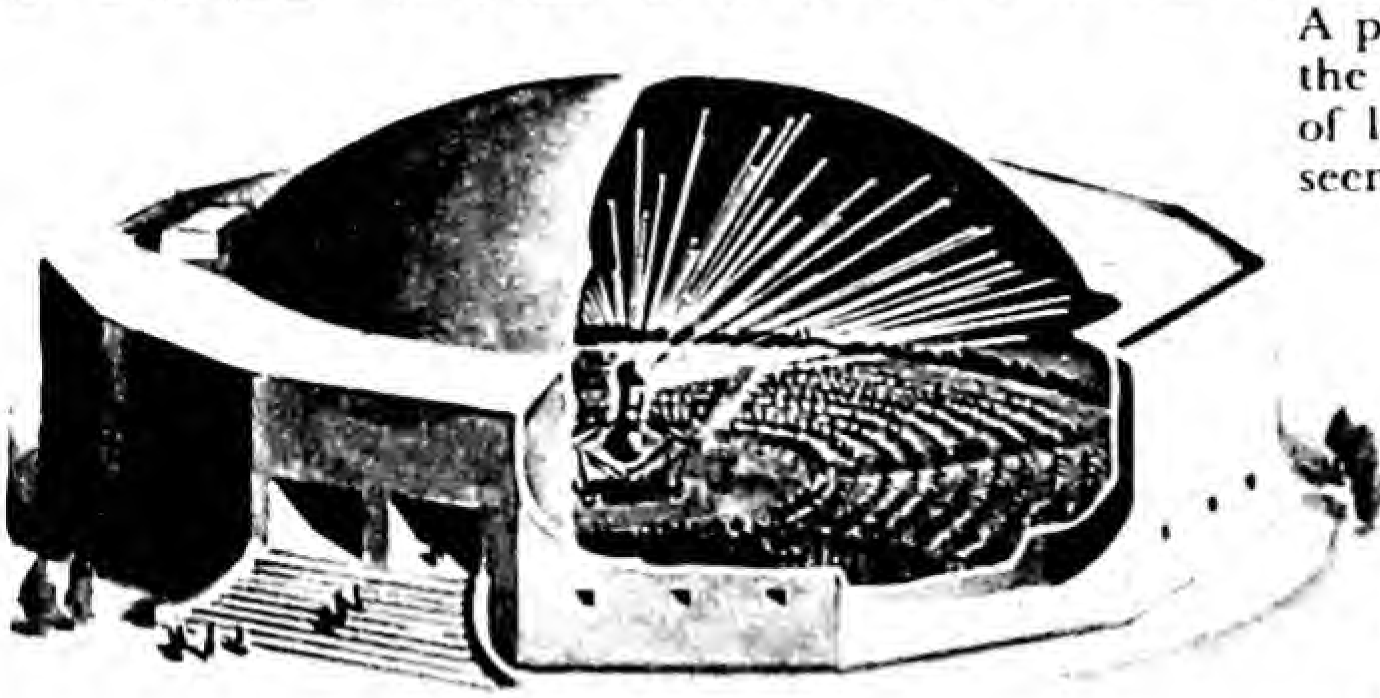


With such large areas to farm, machines do more than one job at once, such as sowing and fertilising.

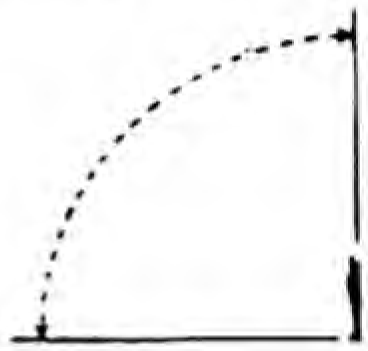
Heavy snowfall in winter reduces farming to feeding cattle in barns and preparing machinery for its summer work. Grain is stored in holders until it is wanted. Most of it is sent abroad.

COMBINE HARVESTERS SWEEP ACROSS THE WHEATFIELDS

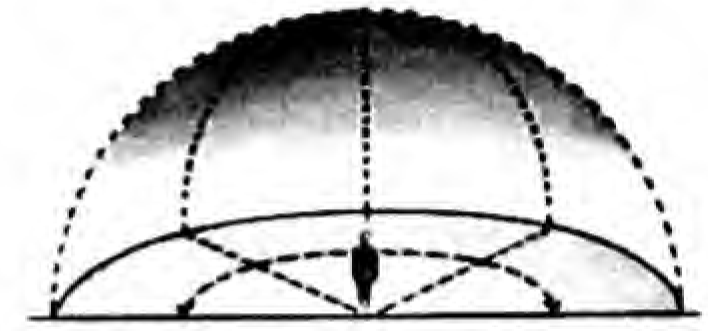
THE ASTRONOMER AT WORK



A planetarium (*left*) has a domed roof that seems like the night sky, because a machine projects on it dots of light like the stars and planets as they might be seen at any time or from any place.



The area you can see looking straight up and down.



Looking up and down and sideways you can see this area.

If you want to prove to yourself that the earth is turning on its axis, as you have been told, you need to make maps of the stars as the astronomer does. (*See pages* 168-173). These maps show how the stars regularly pass across the sky. If you live in New York or one of the other cities where there is a planetarium, you can sit and watch in minutes movements of the stars that in time took a thousand years.

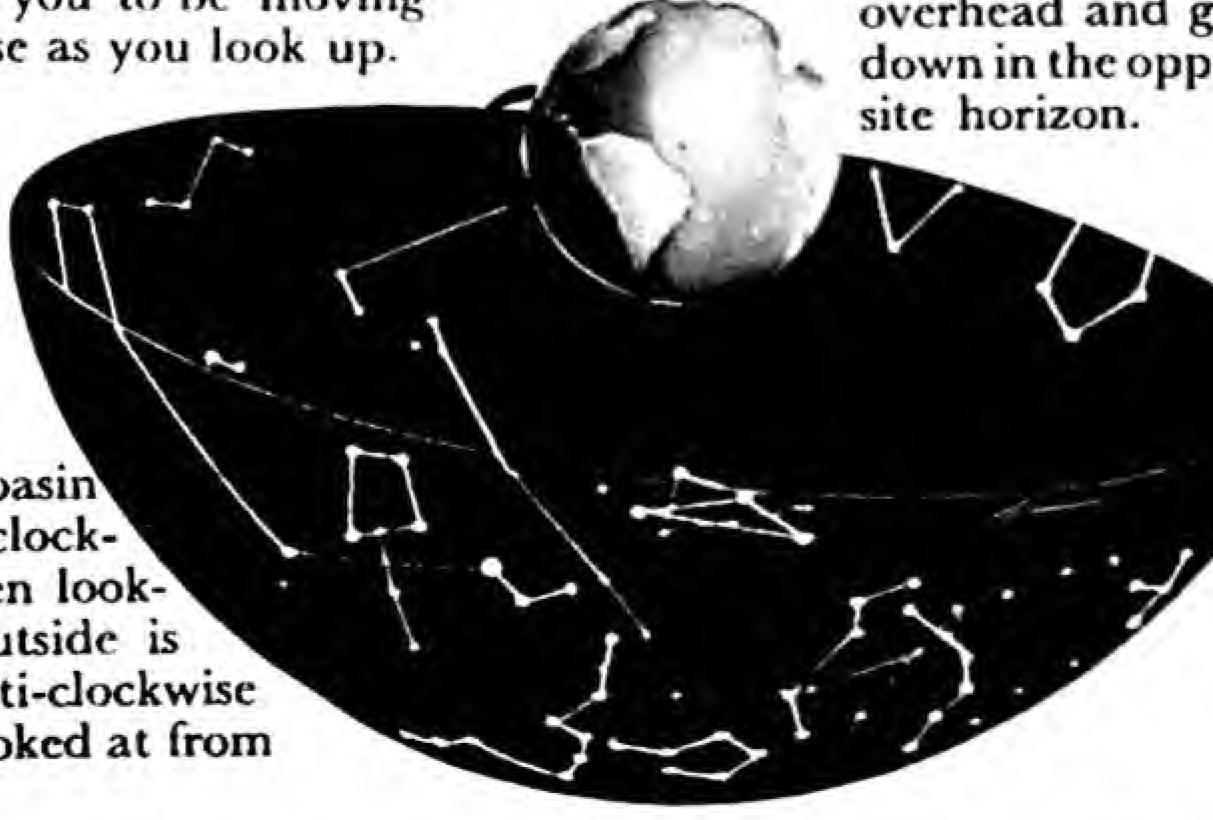
Why the stars seem to move

The way the stars seem to move depends on where you are. The dome of the sky that you see by turning around is called a celestial sphere (although you only really see half a sphere).

These models are drawn from a viewpoint right out in space—there is of course no such thing as a shell around the earth but it is convenient to pretend there is and mark on it where the light of the stars would fall. *But* when you stand on the earth, and look up at the stars you see the celestial sphere from *within*. The constellations will look different to you if you are in the Northern Hemisphere and they will seem to move in an *anti-clockwise* direction. If you are in the Southern Hemisphere *clockwise*.

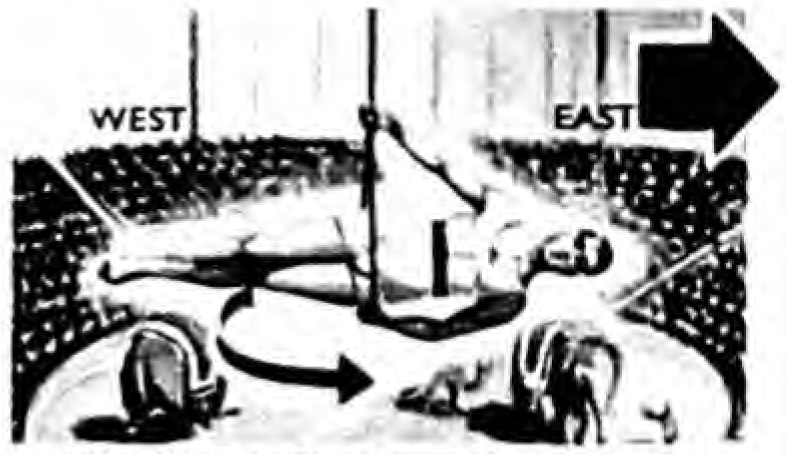
In northern parts of the earth the stars seem to circle anticlockwise as you look up. Towards the South Pole a different lot of stars seem to you to be moving clockwise as you look up.

On the equator the stars come up over the eastern horizon, pass overhead and go, down in the opposite horizon.

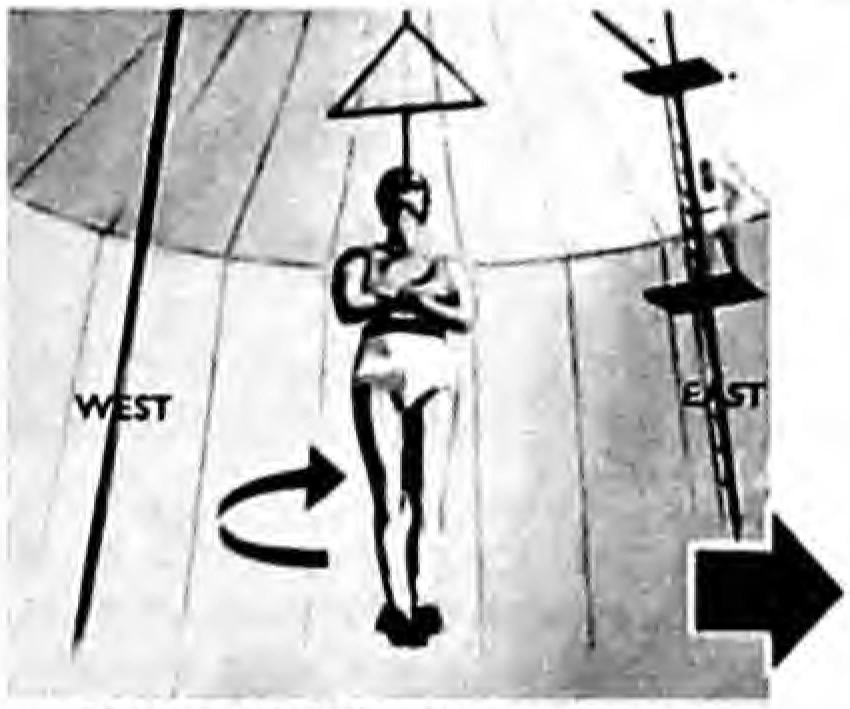


A sugar basin turning clockwise when looked at outside is going anti-clockwise when looked at from inside.

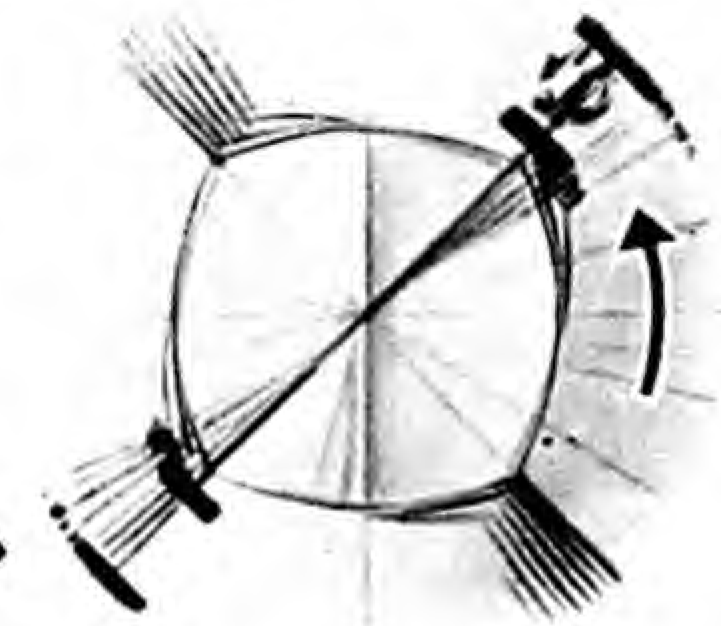
For the stars to be moving differently when you look at them from the equator than when you look at them from North or South of it, does, at first, seem odd. But this is the result of the earth spinning and your change of position. The pictures of the trapezist show that as he twirls round in the middle of the tent the things he sees seem to be going the opposite way. Firstly as he hangs by his tèeth and turns round from west to east he sees the roof going round him anti-clockwise. Only one point keeps still—the top of his trapeze rope. That is what astronomers would call his North Celestial Pole. They would call the rope itself his axis, for he is turning round in that line, as the earth is turning on its axis.



LOOKING WEST AT THE EQUATOR



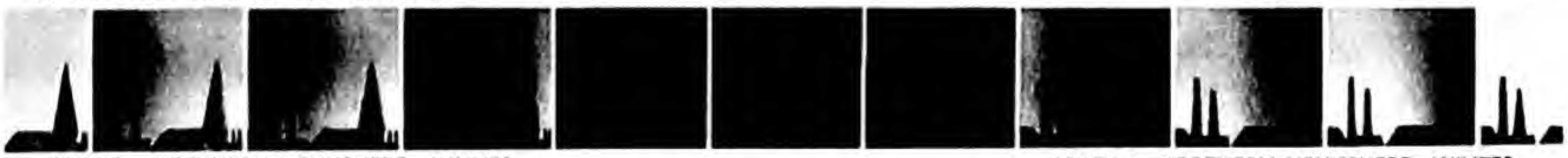
LOOKING UP FROM THE NORTH POLE




LOOKING UP FROM THE SOUTH POLE

Secondly the trapeze is still twirling the same way as he hangs by his feet, and to him he seems to be looking " up " at the floor. And as he sees it, that seems to be going round clockwise. Only the point right under his head does not move.

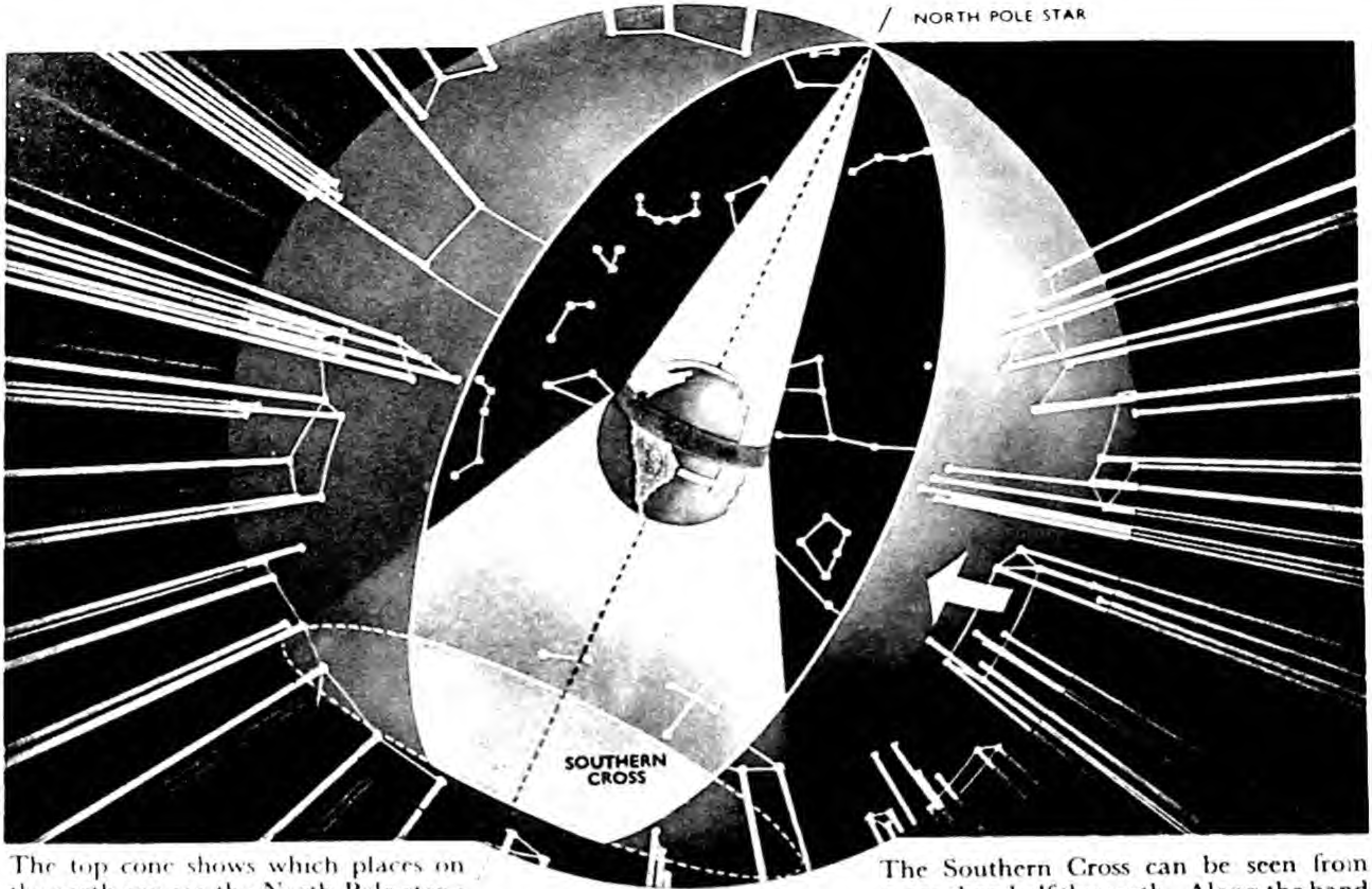
Lastly he hangs horizontally and the audience and elephants seem to be on their sides moving down an endless ladder.



ABOVE: NORTHERN HEMISPHERE—SUMMER   BELOW: NORTHERN HEMISPHERE—WINTER

7 P.M. | 8 P.M. | 9 P.M. | 10 P.M. | 11 P.M. | 12 MID. | 1 A.M. | 2 A.M. | 3 A.M. | 4 A.M. | 5 A.M.

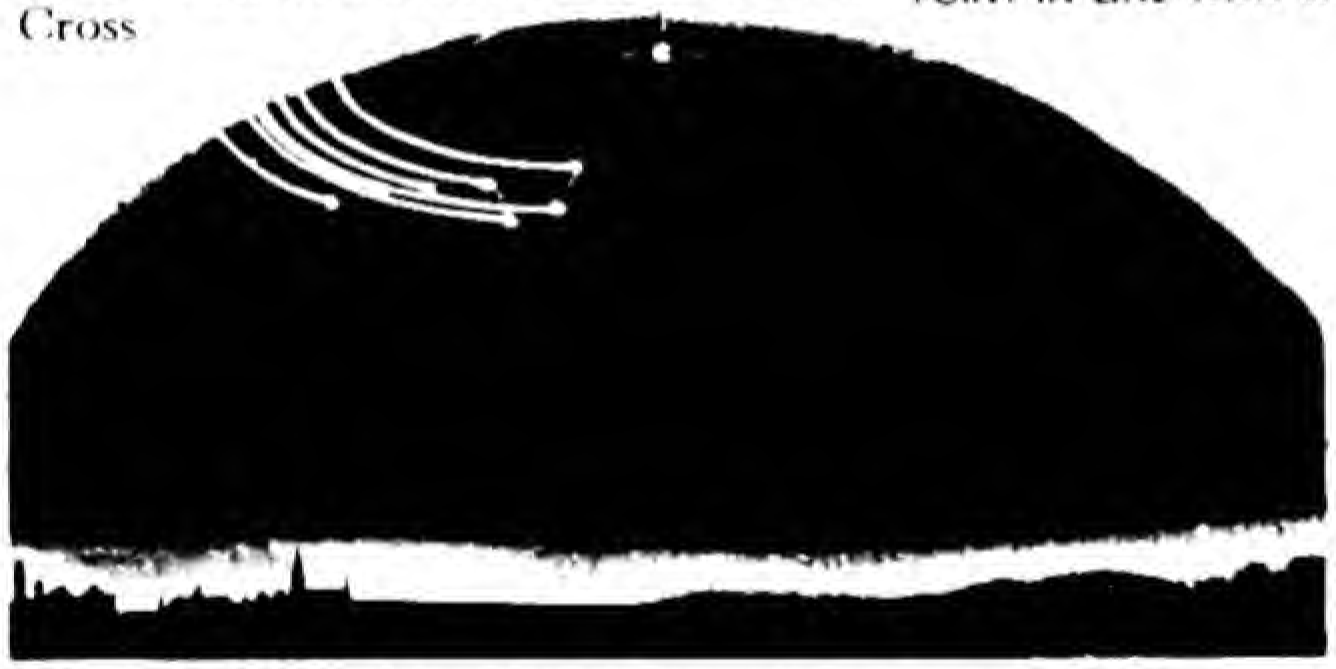
You cannot see the stars complete their circle in daytime because the sun is too bright, but when the nights are long astronomers see a bigger part of the circling than on short nights, so it is safe to say " they seem to go round in a circle ".



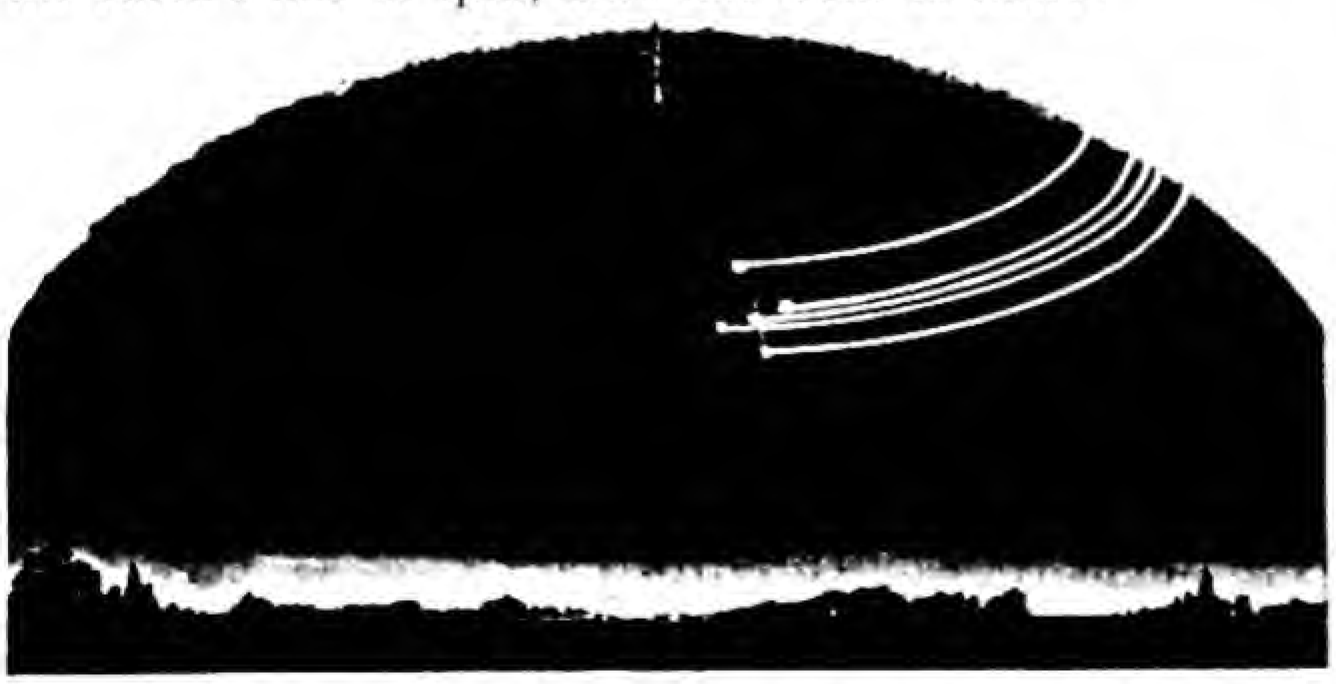
The top cone shows which places on the earth can see the North Pole star; the bottom which can see the Southern Cross.

SOUTH CELESTIAL POLE. AN IMAGINARY POINT IN LINE WITH THE EARTH'S AXIS

The Southern Cross can be seen from more than half the earth. Along the band both N. P. Star and S. Cr. can be seen. A few constellations like Orion can also be seen from both hemispheres.

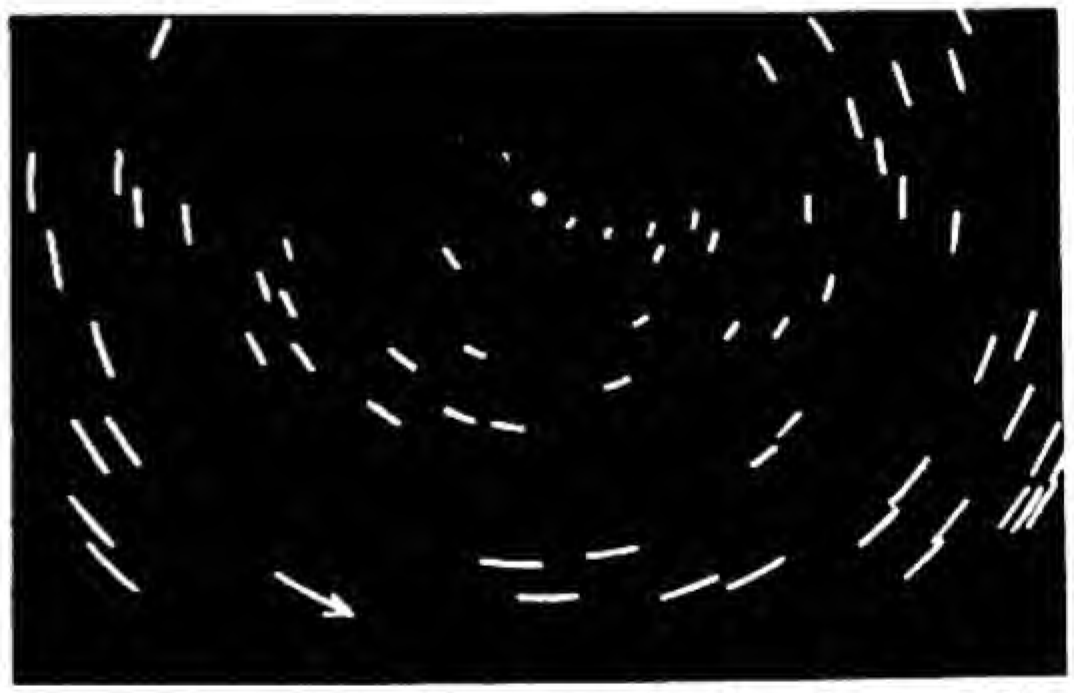


The North Pole Star, by chance almost exactly in line with the earth's line of spin, does not seem to move.

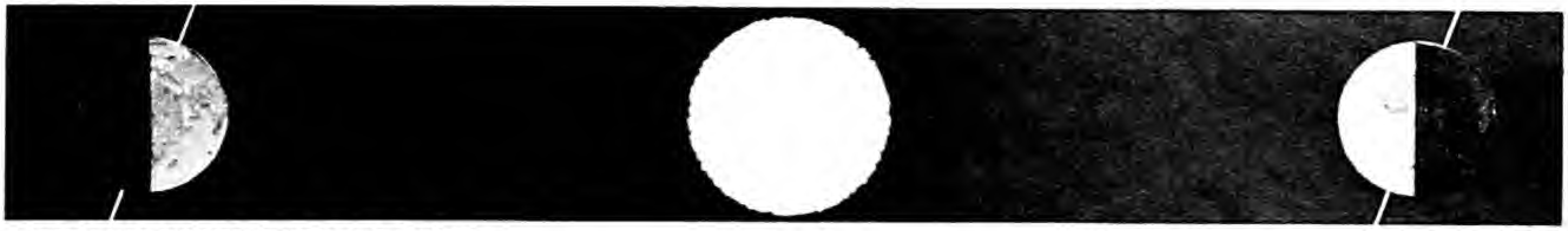


There is no star in line with the southern end of the earth's axis, so astronomers measure the centre of the circle made by the Southern Cross and call that the South Celestial Pole.

In order to record very exactly where each star is at a certain time, astronomers pretend that its light makes a spot on an imaginary spherical screen surrounding the earth. The Celestial Sphere circles from East to West, the opposite way to the earth.



A time exposure photograph aimed up at the North Pole Star (*top arrow*), would show the other stars as light streaks because the camera is twirling with the earth.



NORTH HAS SUMMER, SOUTH HAS WINTER

When the night shadows fall like this people north of the equator get shorter nights. Around the North Pole there will be no night for it does not spin into the shadow.

Longer nights in winter and shorter nights in summer are caused by the tilt of the earth. As you can see the shadow line that separates day and night takes in a larger part of the one hemisphere or the other, according to which side of the sun the earth is. The earth is tilted at an angle of 66½° from the plane of its orbit, or as it is sometimes put, the shadow moves 23½ degrees each side of the equator every year.

SOUTH HAS SUMMER, NORTH HAS WINTER

Six months later there will be no day round the North Pole for it is never out of the shadow. But south of the Equator it will be summer with its longest days.

The curve of the earth prevents this ship being seen from the land.

As it comes round the curve its masts begin to show.

Now it is above the horizon and people on land can see it.

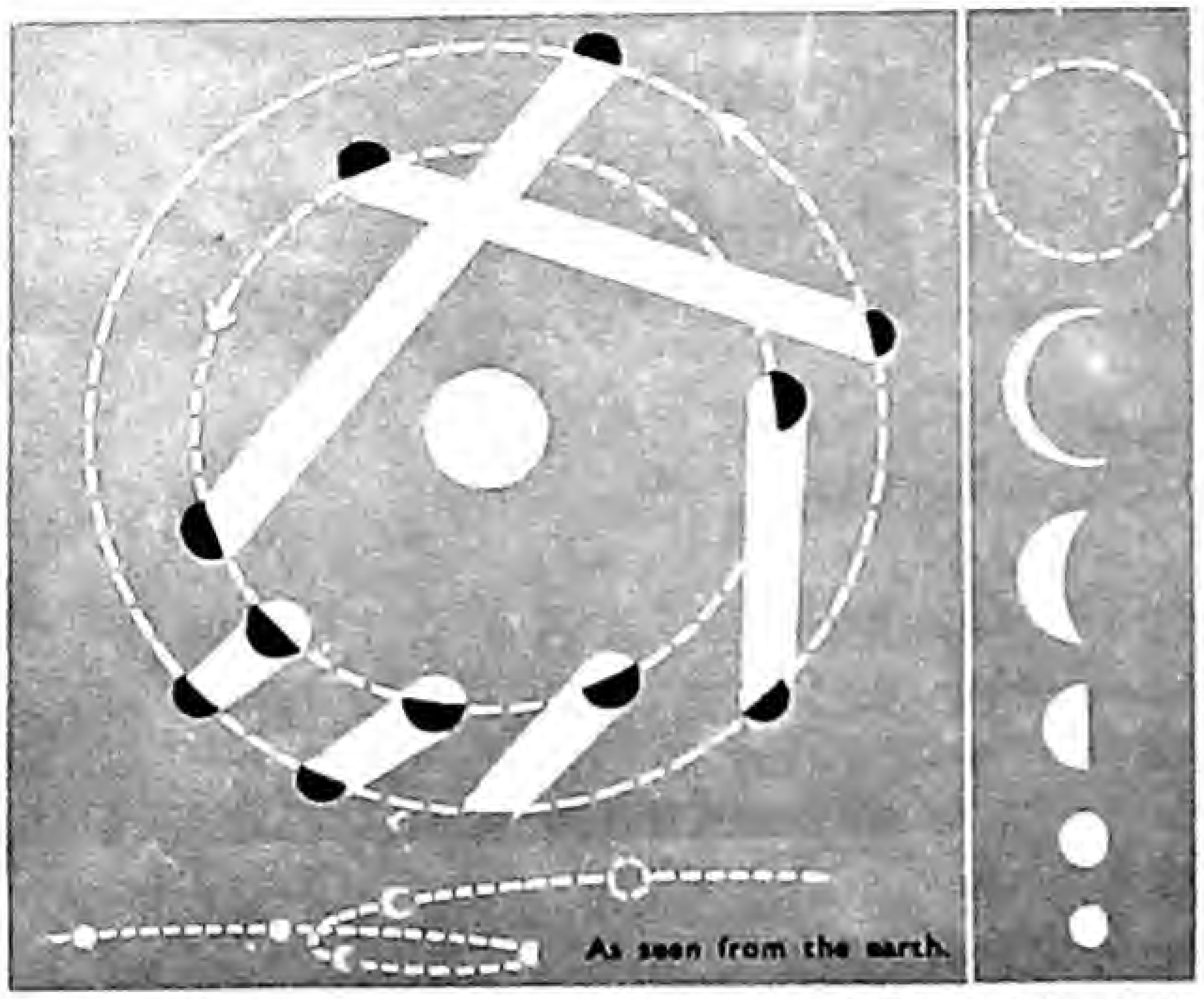
The curve of the earth prevents you seeing some stars.

But as the earth spins it turns our horizon and stars rise.

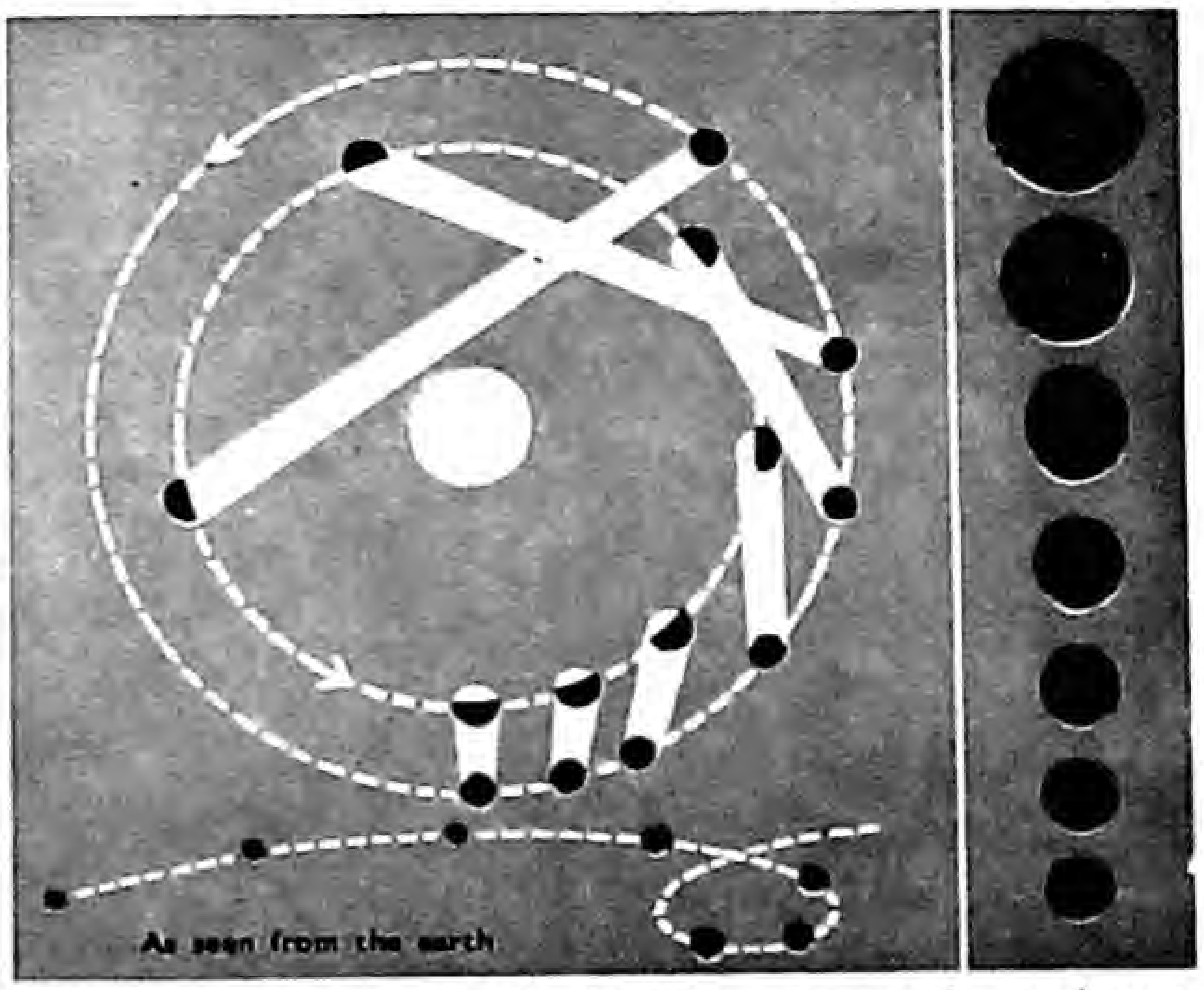
They seem to move past and sink below the other side of our horizon.

Whether or not you see certain stars rise and set depends on whereabouts on the earth you are standing and on the time of year. If you stand at the North Pole or the South Pole all the stars you see will go round and round the sky without going below the horizon. Of course you see a different lot of stars at each pole. Stars like these are called circumpolar. If you look from the British Isles some stars will still be circumpolar, but some, hidden by the curve of the earth, will rise and set. A similar thing happens in Australia, New Zealand and South Africa, though their circumpolar stars are circling the *South* Celestial Pole. The nearer you get to the equator the steeper the stars rise, until right on it stars will rise straight up from the horizon.

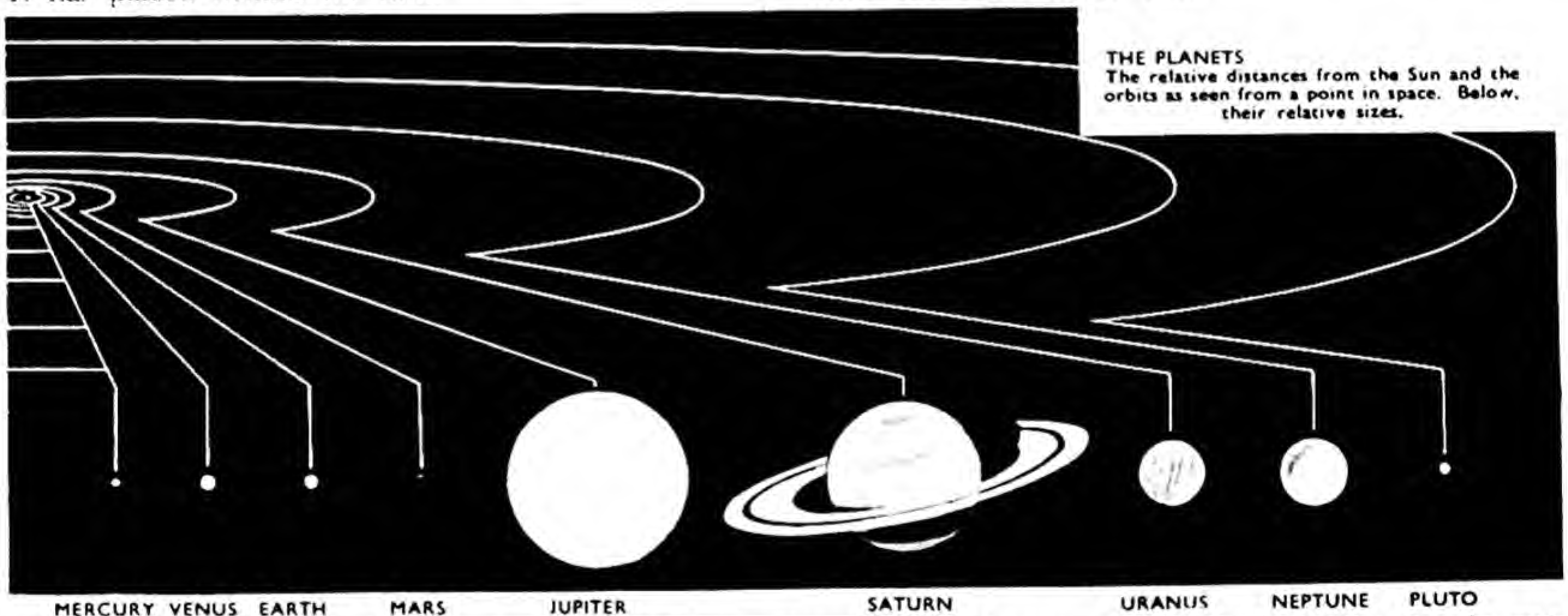
The planets do not behave like the stars. They make strange tracks through the sky as the year passes and they are not always the same size or brightness.



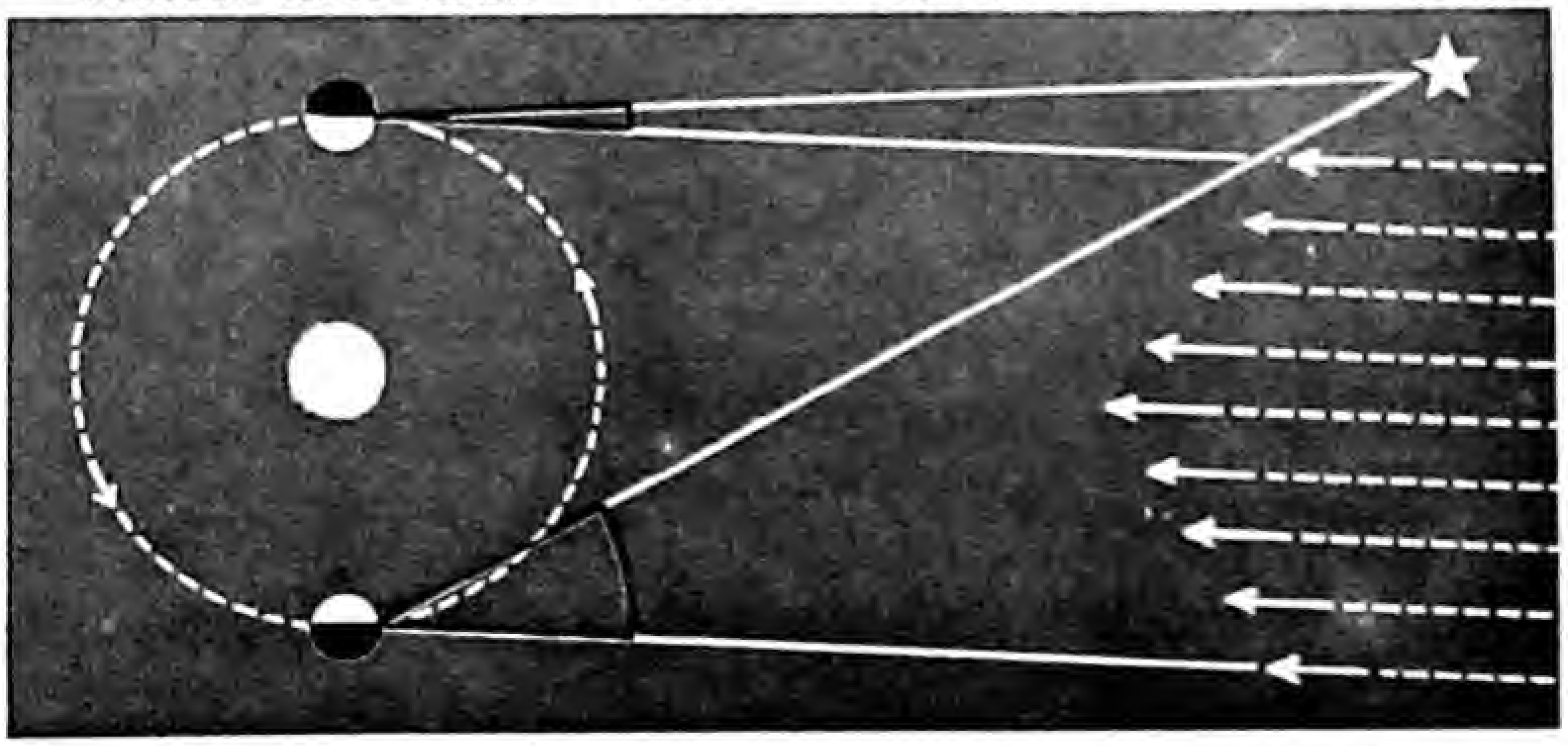
Venus, circling the Sun inside the earth's orbit and moving faster, can only be seen for a short time each morning when on the same side of the Sun as the earth. And of course it shows only a tiny part of its lighted surface. But as it gains on the earth we see its full surface lighted, though much smaller, for it is on the opposite side of the Sun and it soon appears in the sky as the evening star instead of the morning star. It has passed behind the Sun.



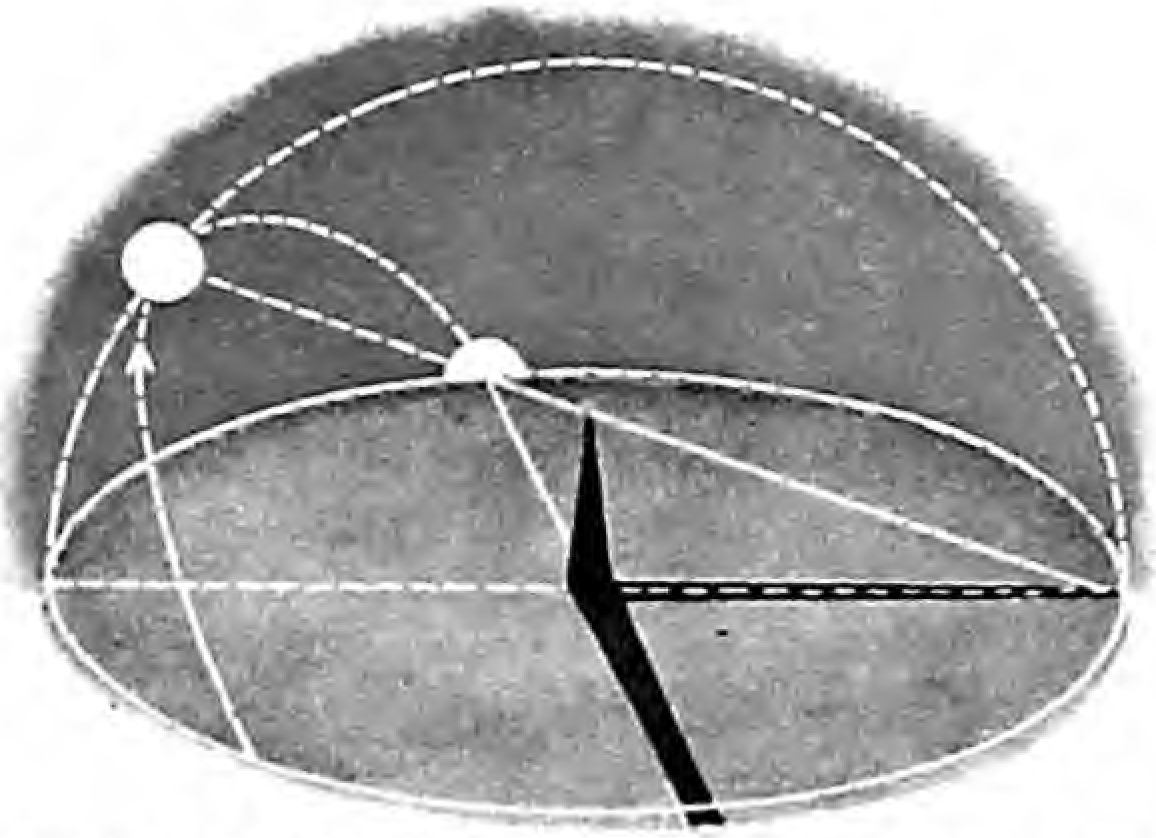
Mars, circling more slowly than the earth, and outside our orbit always shows its most lighted surface, but we look back at it. During the nearly two years it takes Mars to circle the Sun it seems to make a loop, then cross the sky, disappear behind the Sun, and appear again at the other side of the night sky travelling in the other direction. This is all because the earth has made nearly two circuits of the Sun while Mars has made one.

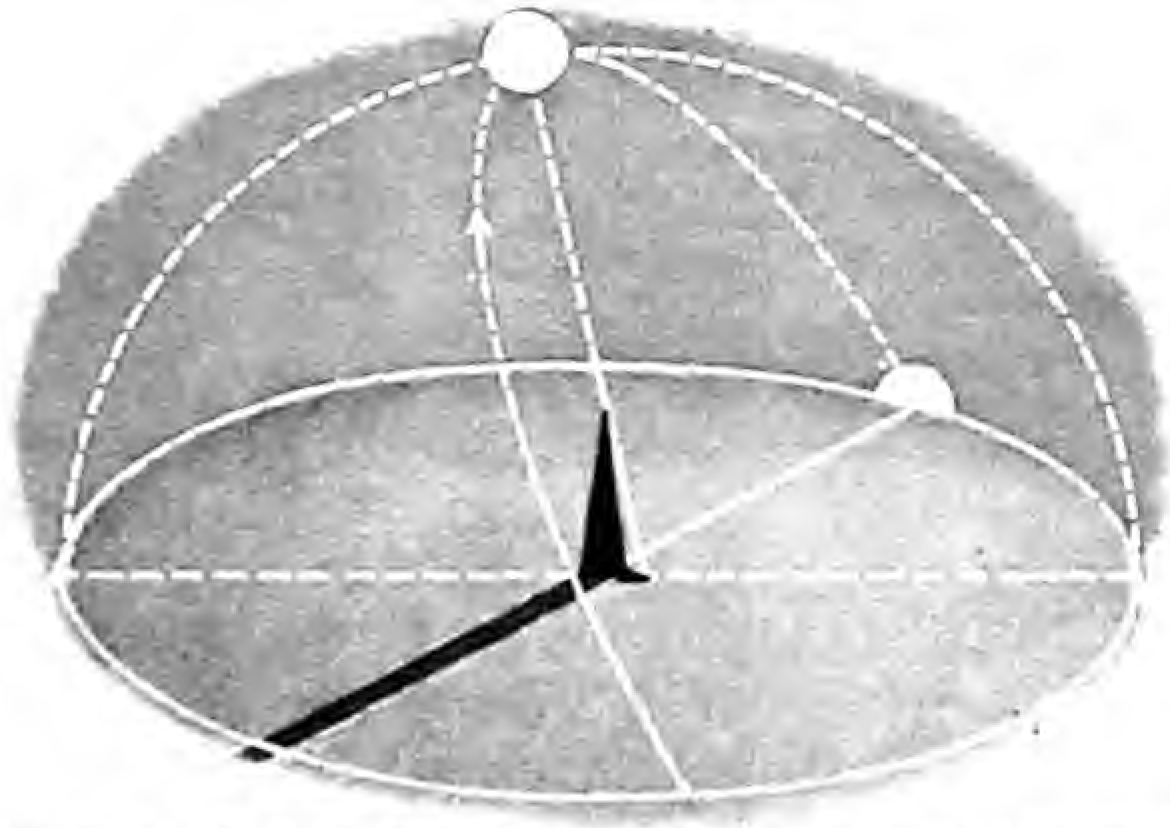


THE PLANETS
The relative distances from the Sun and the orbits as seen from a point in space. Below, their relative sizes.



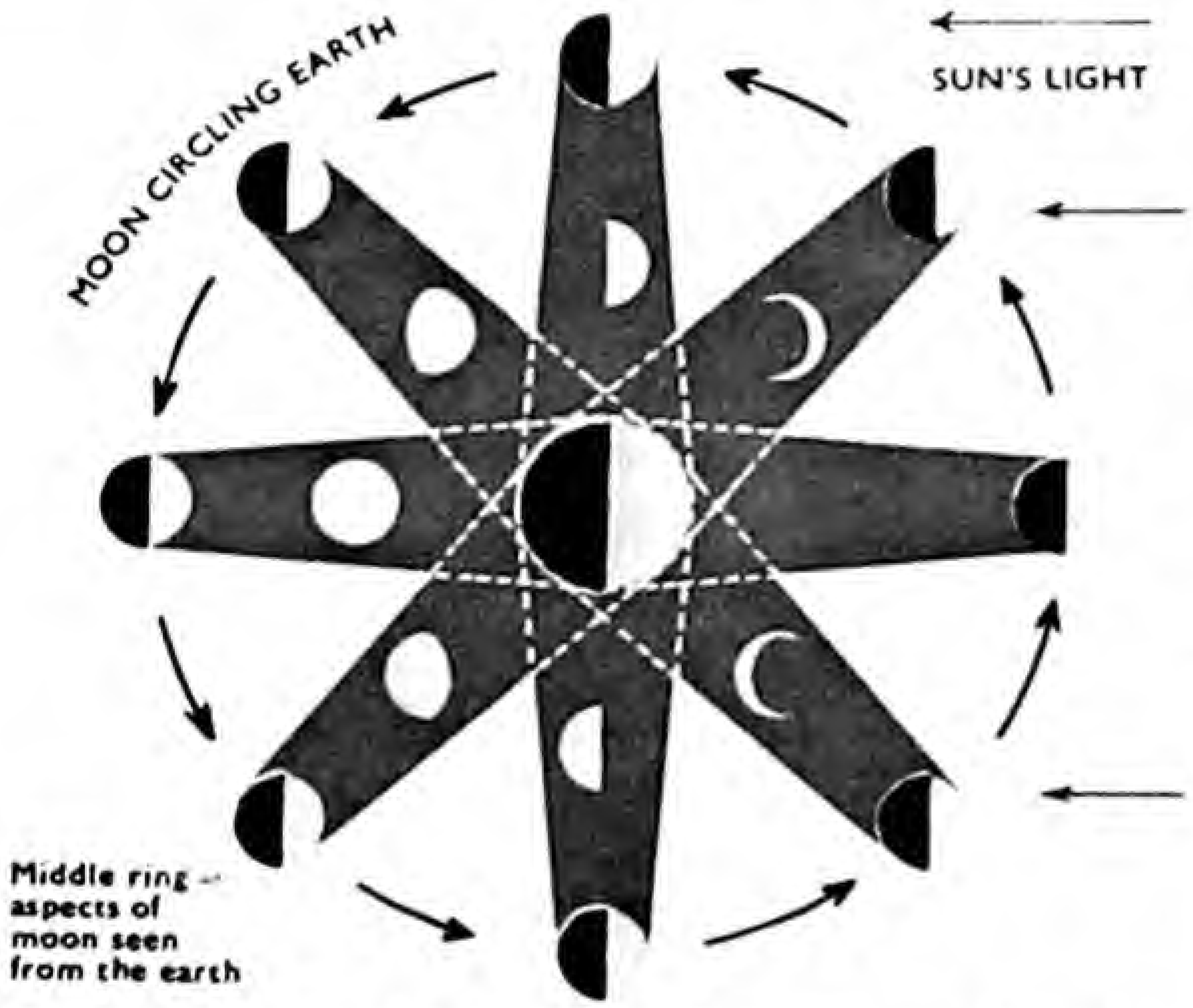
Measuring the distance of a star in our galaxy takes six months. Astronomers take the angle of light coming from one of the distant stars in a far off galaxy. Because it is so enormously far away, this angle will not be any different when measured at the far side of the earth's orbit, 186,000,000 miles away. But the angle of the nearer star will have changed when it is looked at from this new position and so astronomers can draw a triangle and calculate its distance. This is called Parallax.



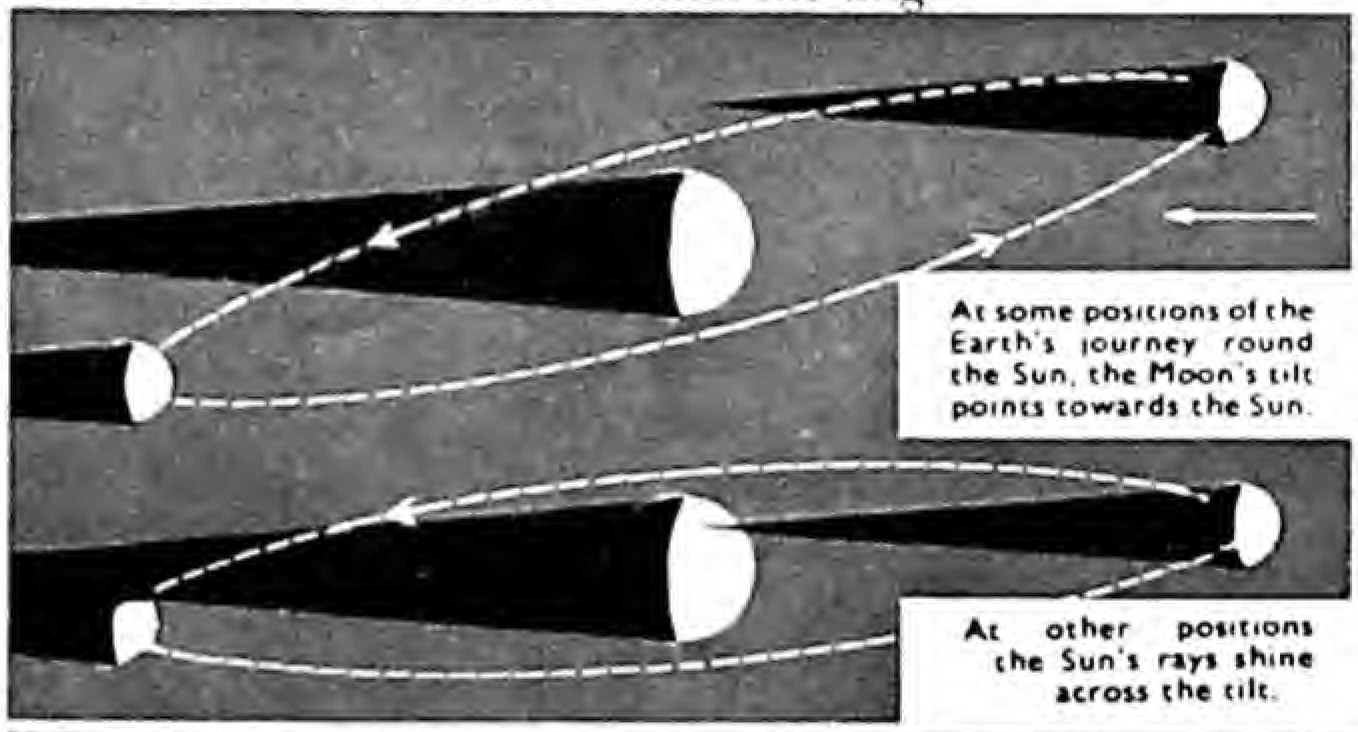


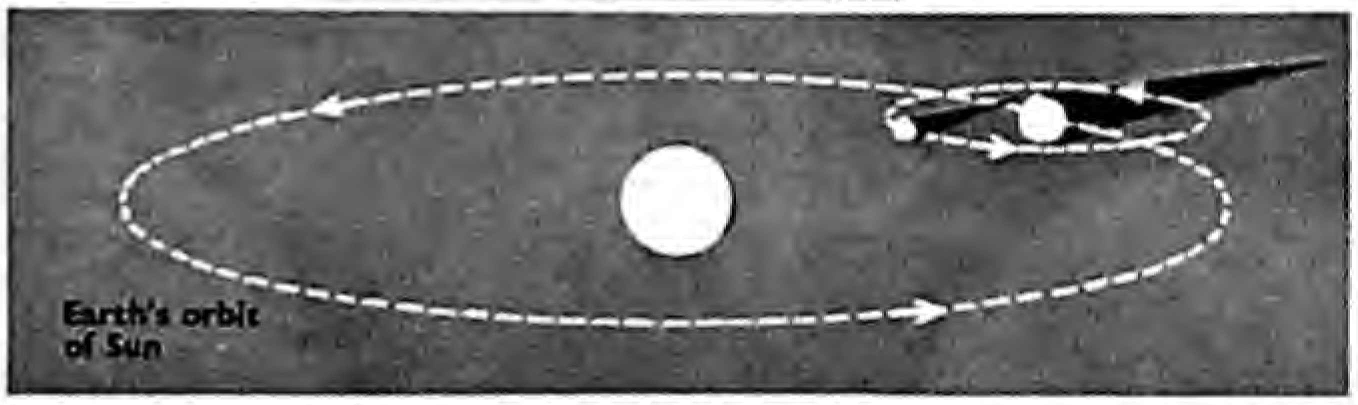
At its highest point the Sun casts a long shadow in winter because it is lower in the sky. The direction of the setting Sun's shadow shows its course is shorter and the day is short.

In summer the Sun is high in the sky at midday and its course is longer. This is only a different way of saying that the tilt of the Earth on different sides of the Sun makes us look at the Sun from a different angle.

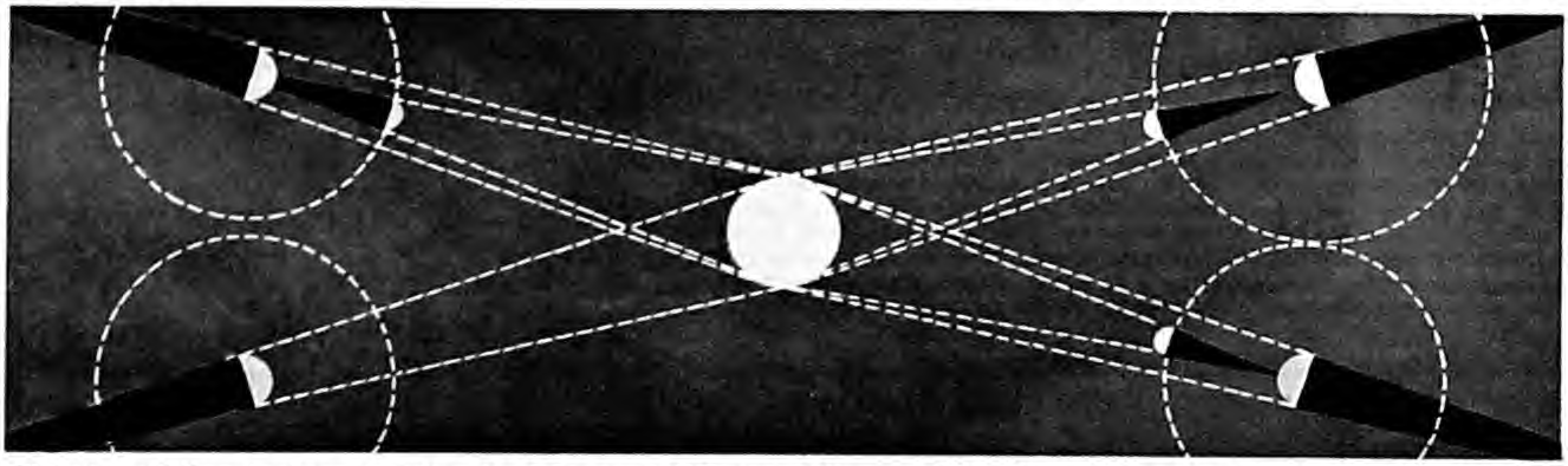


We can only see the Moon when we are facing away from the Sun. This shows why it is full Moon when the Moon is farther from the Sun than we are.



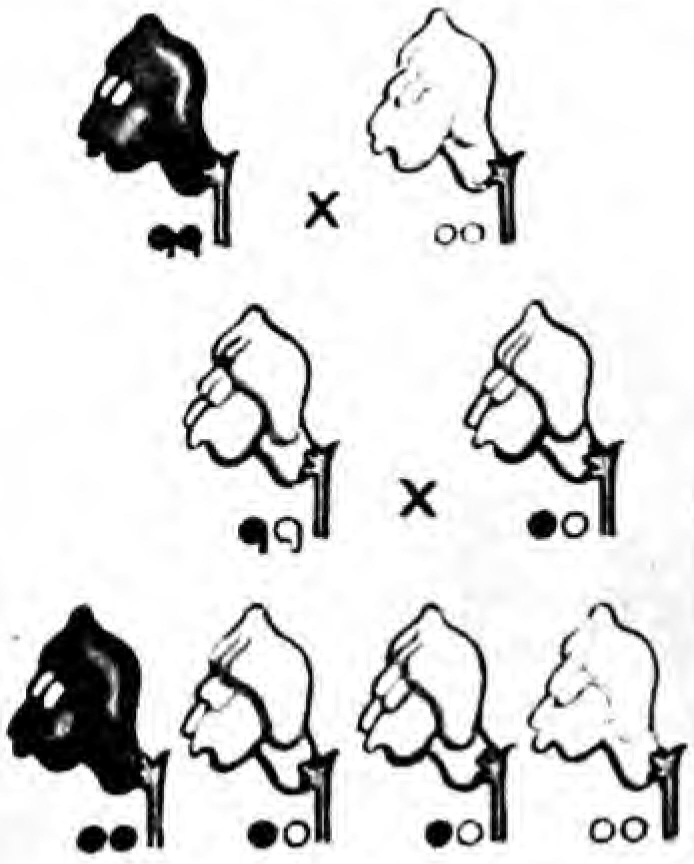


An eclipse of the Sun would occur every month if the Moon's orbit kept its tilt turned towards the sun, but it is in line with the sun only at some places on the earth's orbit.

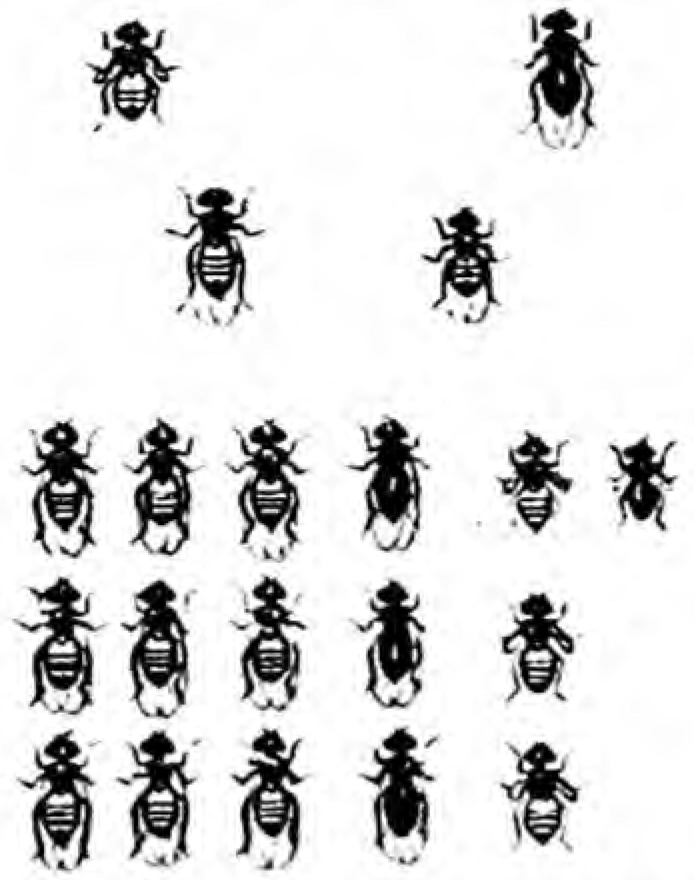


The size of the shadow cast by the Moon at different eclipses of the Sun made astronomers realise that the Earth's track round the Sun was not exactly circular. When the Earth is closer to the Sun, so is the Moon, and its cone of shadow will be shorter (*see page 113*) and (*top left*) covers a big part of the Earth's surface. Or (*bottom right*) further away only long enough just to touch its tip on the Earth's surface. Or (*top right*) not reaching the Earth's surface at all. Bottom left shows a total eclipse of the Moon.

PARENTS AND PROGENY

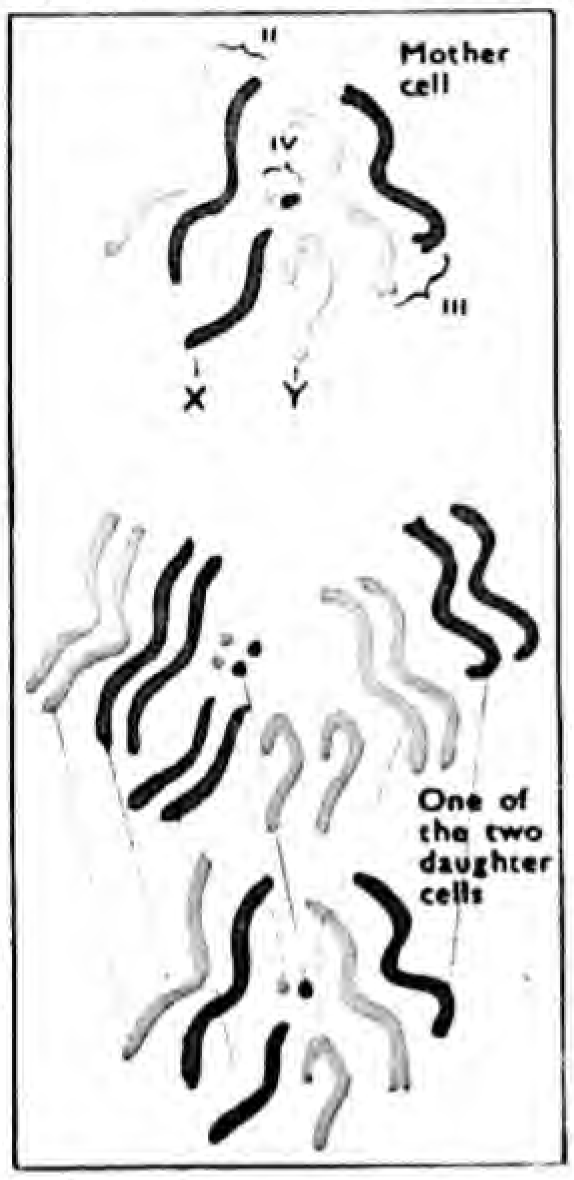


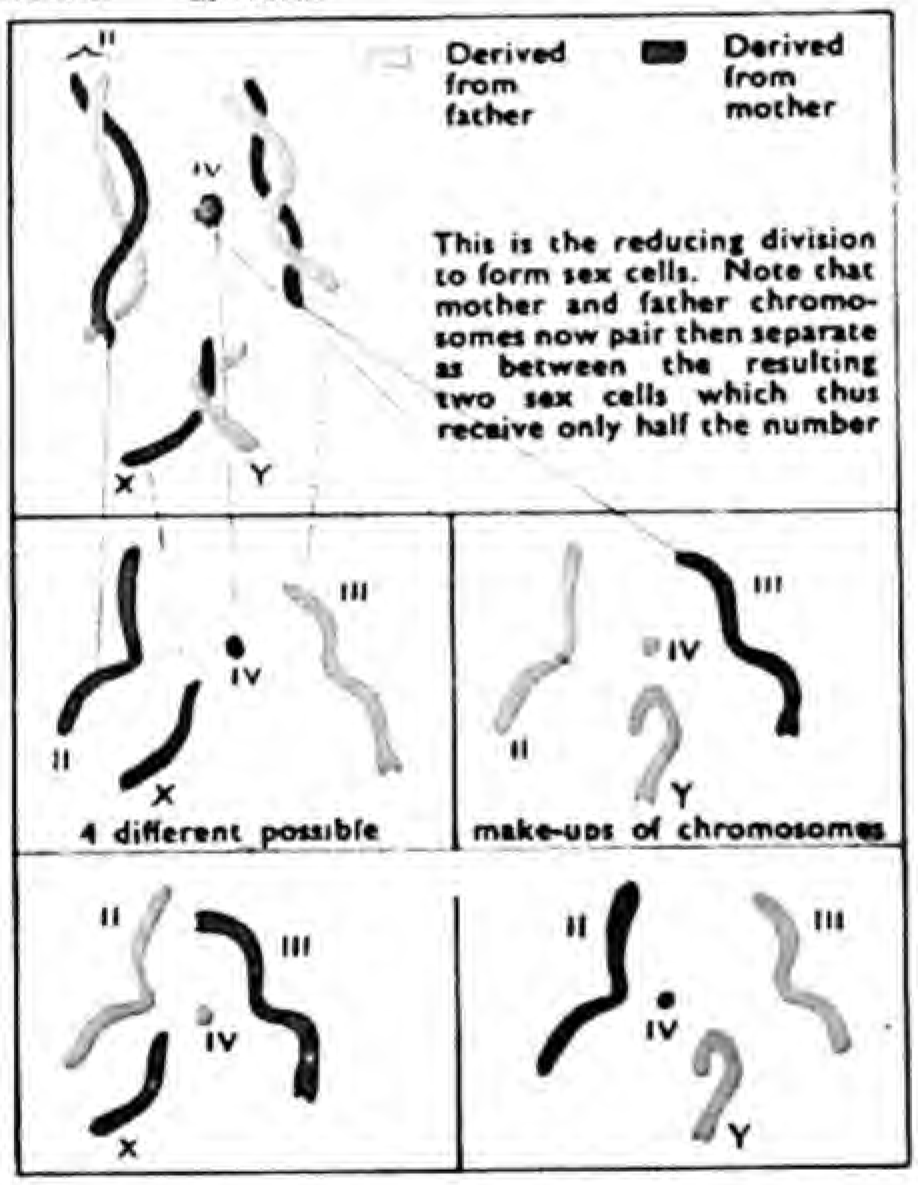
Crossing purebred red and ivory antirrhinums gives only pink-flowered plants. Each hybrid must contain one red and one white inheritance factor. When these are inbred their progeny show how separation and remixing of these factors during reproduction produces red, pink and white forms in fixed proportions.



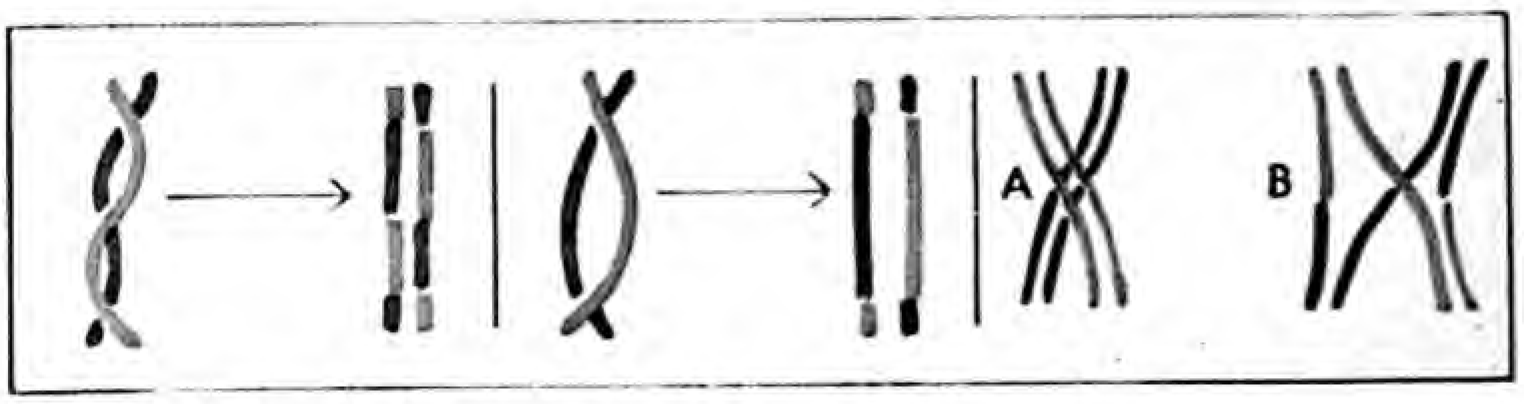
In fruit flies some traits (big wings, striped body) override others (little wings, ebony body). Thus first generation flies though hybrid, unlike antirrhinum, do not show blending. But their varied offspring which come in proportions shown reveal heredity at work.

In man as in fruit fly some traits (dominants) override others (recessives). In humans blue eyes and blond hair are recessive. If two brunette parents both carry these recessive genes (i.e. are hybrids) some of their children may be blondes. Where each parent is a blond (i.e. is free from dominant traits) the children are all blondes. Actually hair colour and eye colour are inherited through separate heredity factors, and it is possible to have dark hair and blue eyes.





Traits are the expression of the action of heredity factors called genes. These are carried in the various pairs of chromosomes found in all the cells of the body. When cells divide to produce growth each chromosome splits lengthwise, and the two cells both receive a full set exactly like the old cell. In division to produce sex cells the chromosomes of each pair separate at random, each sex cell receiving half of the original number. Pairing also involves twisting together and an exchange of parts as below. Later union of the sex cells restores chromosome number but the genes will be in new assortments.



Dominant and recessive characteristics are proved in the total numbers of different types of progeny resulting from breeding. Of course it is a great deal quicker to breed from insects which produce huge numbers at each generation, but breeding from two herds of cattle exactly similar to the single first parents shown would, within a fairly short period of years, actually produce the numbers of crosses shown. Sometimes such calculations are merely done by proportion of the types born among a smaller number.

There are two ways in which parents can be related to their offspring. Increase, or propagation, may occur by budding or division. This is a common method in plants, but it is also found in some of the simpler animals. In this method, known as vegetative because of its commonness amongst plants, the young are indeed "chips off the old block", being identical with their parent, except on the rare occasions when a "bud sport" occurs in the process and gives rise to a novelty.

The other method requires the union of two different cells to produce the new generation, and is known as the sex method. It occurs both in the plant kingdom, where we find ovules fertilised by union with pollen grains, and in the animal world, where eggs become capable of development after uniting with a sperm. Each offspring brought into existence in this way represents a new beginning. It is *not* a "chip off the old block" but a novel combination of qualities peculiar and unique to itself. Heredity determines how it will shape.

Heredity and Breeding

No progress towards a scientific explanation of heredity was made so long as attention was confined to wide crosses between creatures differing in numerous respects, e.g., between breeds of dogs, or between varieties of fruit trees. Mendel (*see page* 92) made the first great advance when he decided to confine his attention to following out the results in several subsequent generations of crossing two varieties of garden (culinary) pea that differed only in respect to the intensity of one characteristic, height of growth.

He crossed pure-bred tall peas with pure-bred dwarf peas by taking away a flower's own stamens and putting on its pistil pollen of the opposite parent. He found that all the progeny in the first generation were alike, and were as tall as their tall parent.

Pure-bred Tall × Pure-bred Dwarf

|

All Tall (first generation or F1) but mongrel (or hybrid) being from unlike parents.

From these hybrid Talls Mendel obtained the next (F2), or grandchildren generation by self pollination. (By choosing a self-fertile plant Mendel had made his work easier). When he raised this F2 generation he found that where he had large enough numbers dwarfness reappeared in one quarter of its individuals.

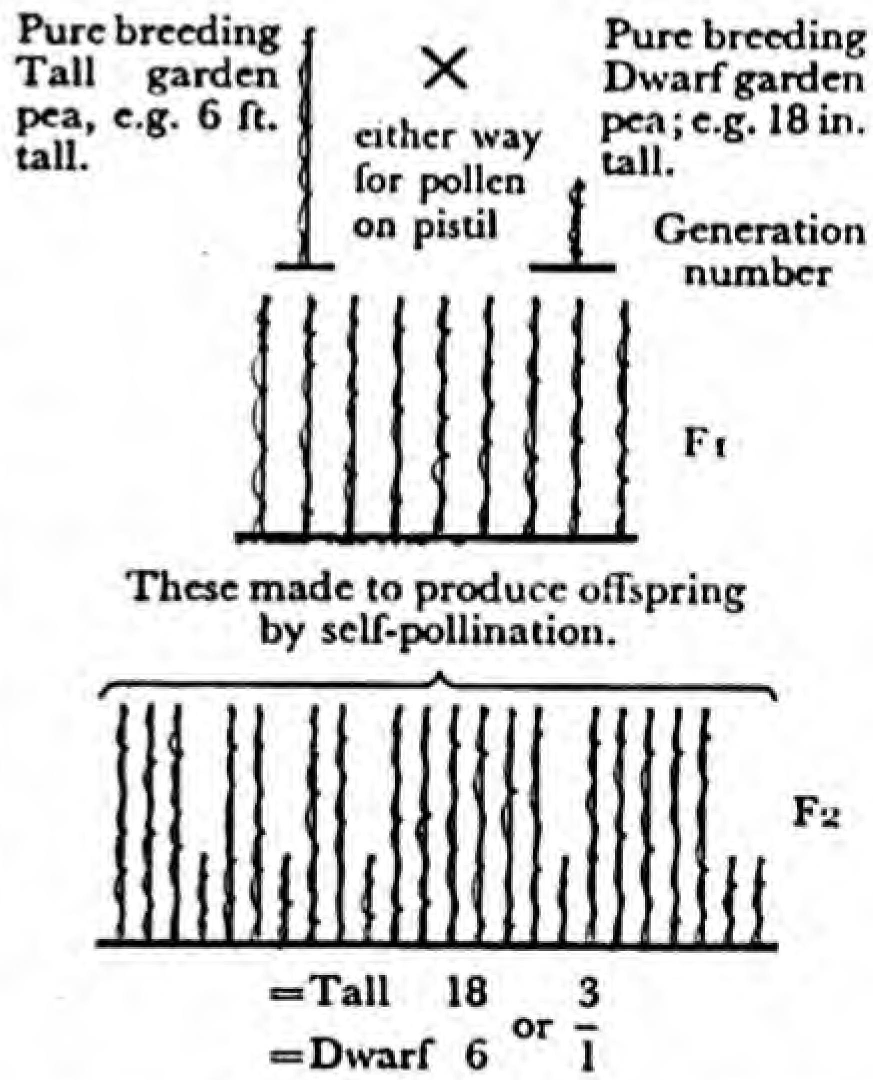
Tall F1 (self-pollinated)

3 Talls for every 1 dwarf (grandchildren generation or F2).

Mendel's genius led him to continue further and to test separately each one of his F2 plants by self pollination. In this way he was able to show that all the dwarf F2 plants were pure breeding, but that of the F2 tall plants only $\frac{1}{3}$ bred true. This must mean that the ratio of types in the F2 is really:

1	:	2	:	1
pure breeding tall		mongrel tall		pure breeding dwarf

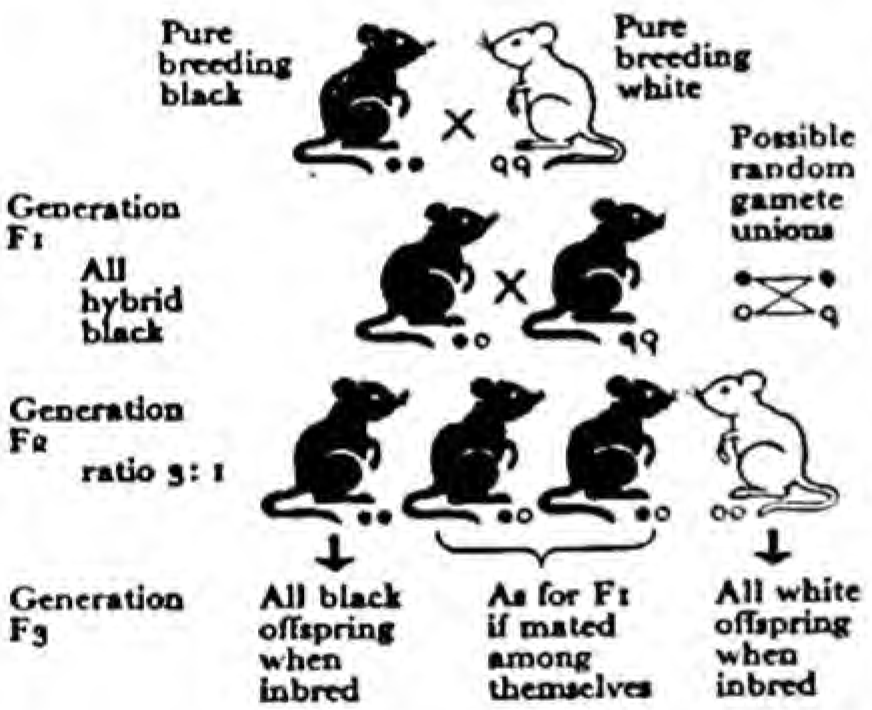
From these facts we must draw several important conclusions. (1) Heredity is not the study of how offspring resemble their parents. It may be their grandparents, or even more remote ancestors that they resemble. Similarly two individuals exactly alike may in fact be of quite different hereditary constitution, e.g. the pure tall and the hybrid tall garden peas. Indeed heredity is only clearly revealed at work where offspring *differ* from their parents, and amongst themselves show unlikeness due to the separation and recombination of those influences that made up the parental nature. This happening is known as segregation. (2) When a trait can skip one or more generations, and yet reappear again untainted, it is said to be recessive in character. In our example, dwarfness is recessive and tallness is dominant. Tallness being a dominant trait can be handed on directly from one generation to another. You can never get tall peas by crossing together dwarf peas, though you can sometimes get dwarf peas by crossing together tall ones.



(3) After crossing unlike purebreds there is found in later generations a simple numerical ratio between individuals bearing the alternative forms of the characteristic being studied. Thus there must be some orderly process at work in heredity (as earlier had been found to be the case in chemical and physical

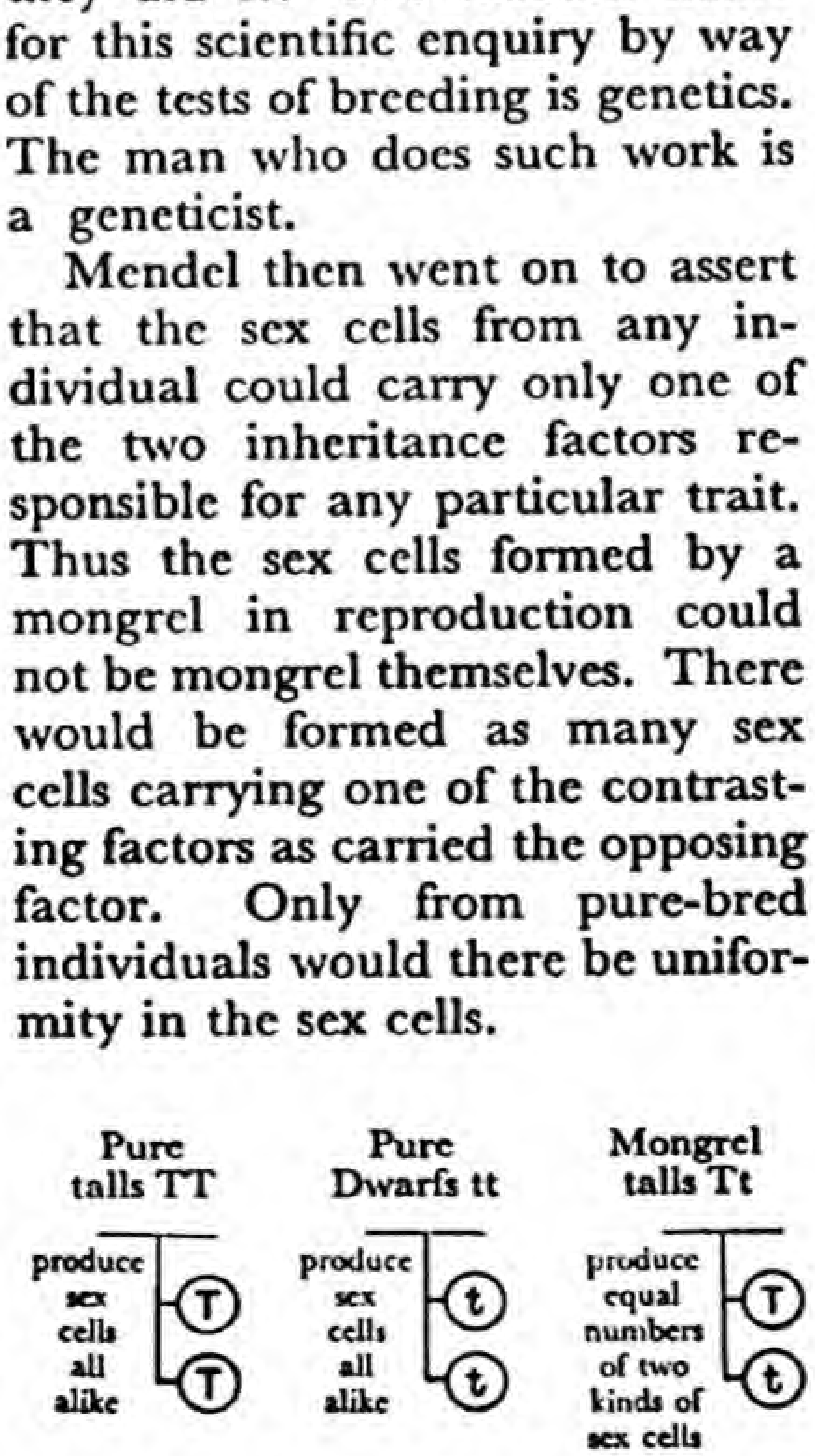
happenings). Heredity would seem not to work by blending, but rather by a conflict of packets or units of inheritance as to which units will express themselves (dominant), and which will be present and able to be conveyed to a further generation though not expressed in the present generation (recessive).

Many similar cases to the cross tall × dwarf in peas came to be known later. In the garden pea yellow-seededness dominates green-seed, round-seededness dominates wrinkled, whilst the condition for having coloured flowers dominates that for white flowers. We illustrate the result of crossing black and white in mice.

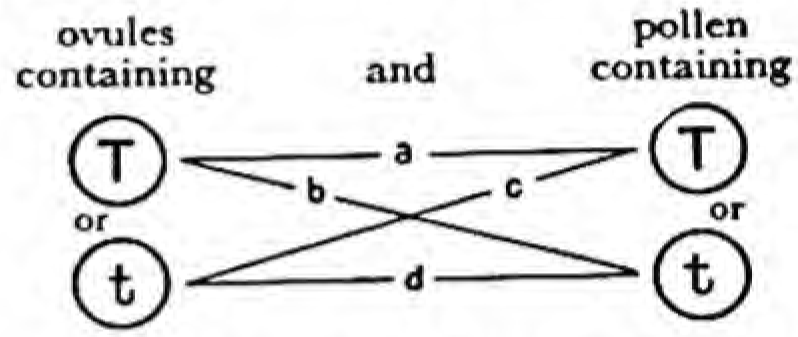


Having discovered the facts by the careful counting of his results Mendel went on to invent an explanation that would fit the facts. At that time very little was known about the way sex reproduction worked and it is remarkable how exactly Mendel anticipated what was later to be discovered. His argument went like this. Each individual is the product of two lines of descent, via the egg and the sperm, and will thus inherit two influences or factors each able to affect the development of the characteristic being studied. Dominant factors are usually indicated by capital letters and the relevant recessive by a small letter. Thus pure bred tall peas are considered to be TT, pure bred dwarfs to be tt and the tall hybrids Tt. Because t, the factor producing dwarfness, is recessive these mongrels (Tt) appear externally to be just like their (TT) pure bred tall parent. Only in the breeding of progeny do they reveal their true condition. This is the only, real measure of any individuals heredity except for a creature of the most inbred kind. (By inbred we mean a creature that is the product of generations of intermarriage with close relatives, a process which tends to increase uniformity in hereditary constiution.) Moreover, it is only by the separation out amongst the members of a later generation of the abnormal state of some characteristic that the mode of inheritance of the normal state can be found out. If all peas were tall we would have no idea how they did it! The modern name for this scientific enquiry by way of the tests of breeding is genetics. The man who does such work is a geneticist.

Mendel then went on to assert that the sex cells from any individual could carry only one of the two inheritance factors responsible for any particular trait. Thus the sex cells formed by a mongrel in reproduction could not be mongrel themselves. There would be formed as many sex cells carrying one of the contrasting factors as carried the opposing factor. Only from pure-bred individuals would there be uniformity in the sex cells.



The last assumption Mendel needed to make to explain his results was that in any hybrid mating there is equal possibility for union between any of the various kinds of sex cells. Thus—



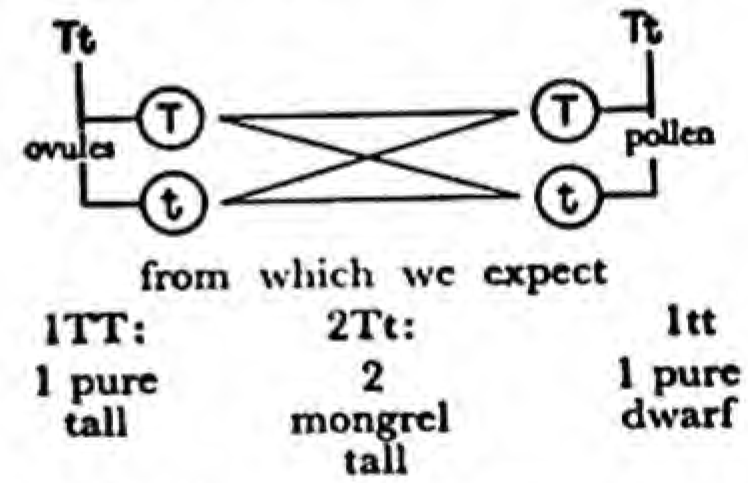
would link up equally readily into each of the four possible combinations.

(a) TT (b) Tt (c) tT (d) tt. Hereditarily, of course, (b) and (c) are the same. If we put this out in the manner of the previous figure for the F1 and F2 generations from pure tall × pure dwarf pea we can see how well the explanation fits the facts.

pure tall (TT) × pure dwarfs (tt)

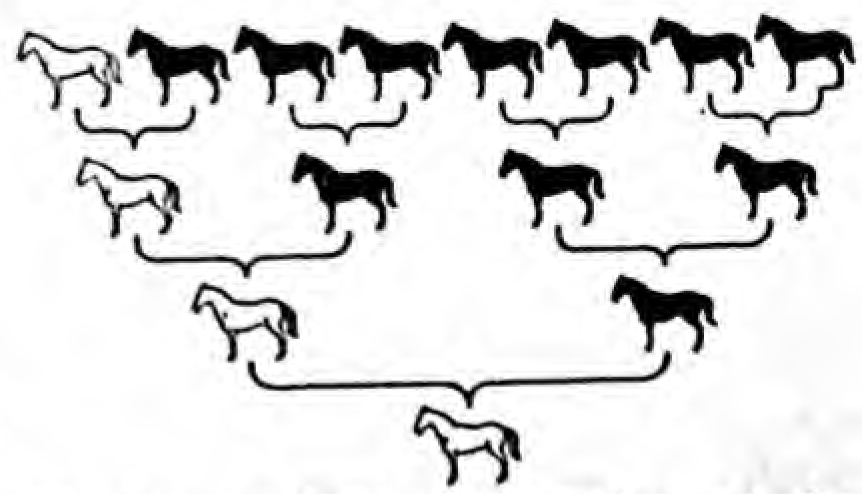
all Tall (Tt) = F1

Two F1 peas crossed or each self-pollinated means—



A similar explanation applies to the cross in mice and is shown in the illustration by the blackness or whiteness of the sex cells.

The diagram below shows how

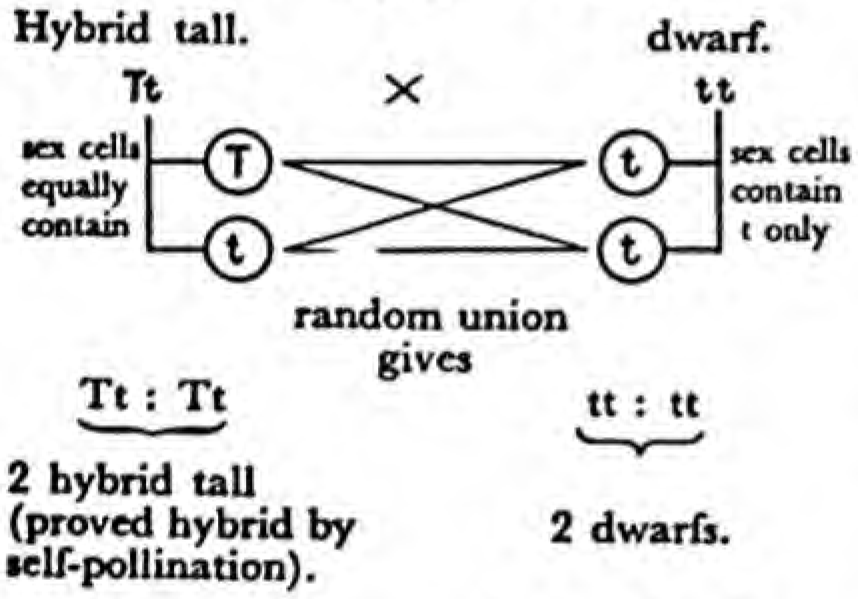


The ancestry of "Tetrarch", a racehorse, showing the dominant "grey".

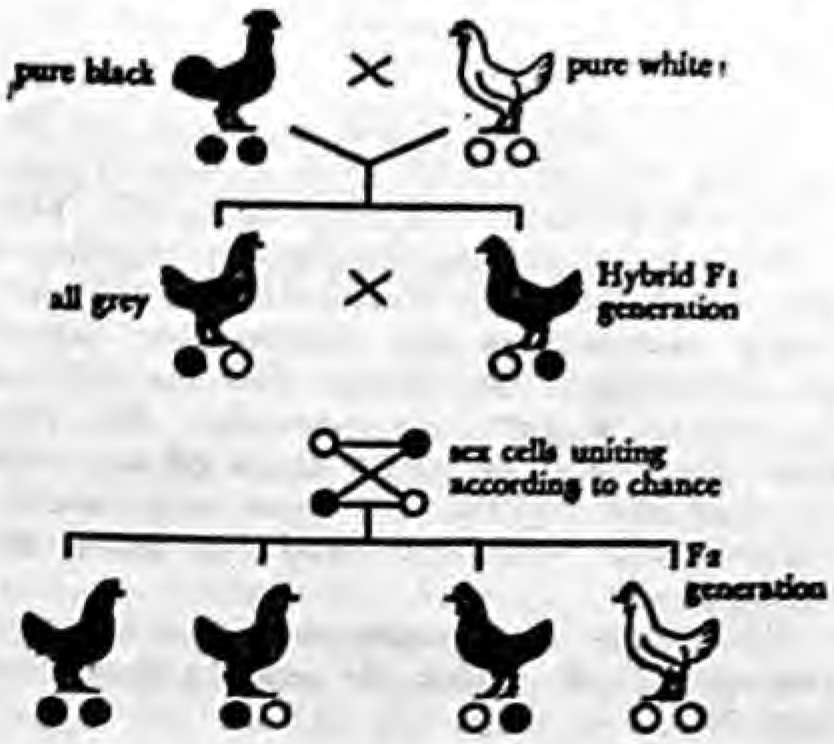
a dominant trait may persist unchanged for many generations.

You will on reflection see that the simple ratios in these examples are only likely to be obtained if large numbers are considered. This is due to the working of chance (if you toss a penny four times you *may* have heads come up four times! If you toss it 1,000 times you are more likely to secure heads in exactly 500 cases, that is in the simple ratio of 1 : 1 for heads : tails).

Mendel sought to test his explanation by using it to foretell what would happen if a hybrid tall pea was crossed back with a dwarf pea. He was able correctly to predict the occurrence of equal numbers of tall and dwarf plants in the resulting generation.



In some crosses instead of one trait dominating another there may be interaction to produce an intermediate state in the hybrids. In these cases hybrids can be recognized without any further testing of progeny. Examples are illustrated for flower colour in antirrhinum (see colour plate 160)

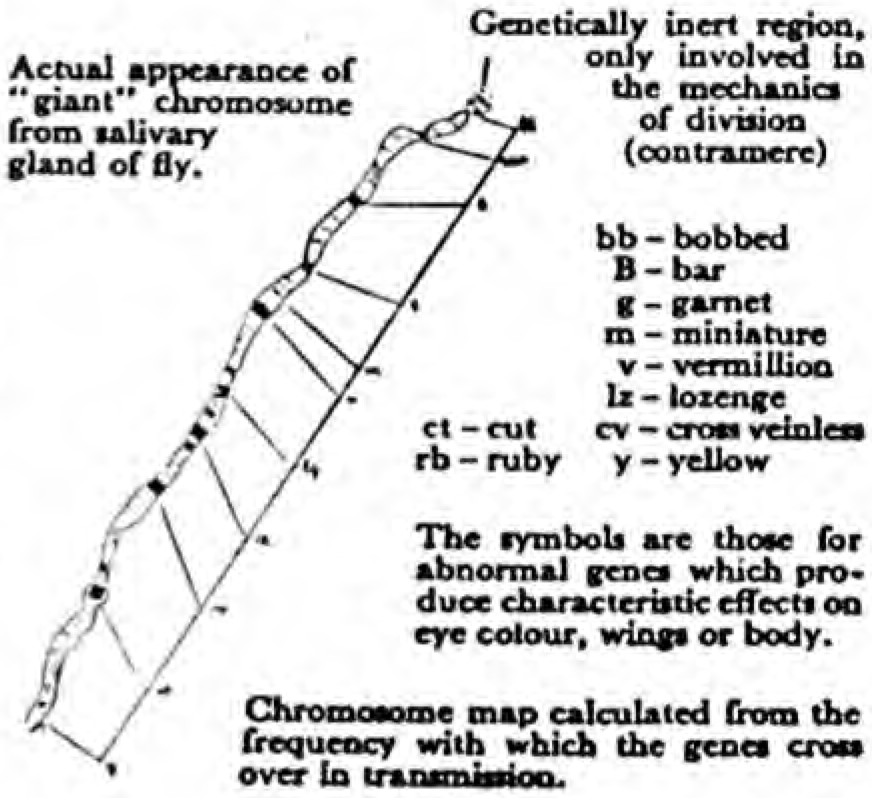


and for plumage colour in fowls. It will be seen that the F2 ratio of 1 : 2 : 1 is only a special case of the 3 : 1 ratio where dominance occurs, since 1 + 2 : 1 = 3 : 1

The Chromosomes and Breeding

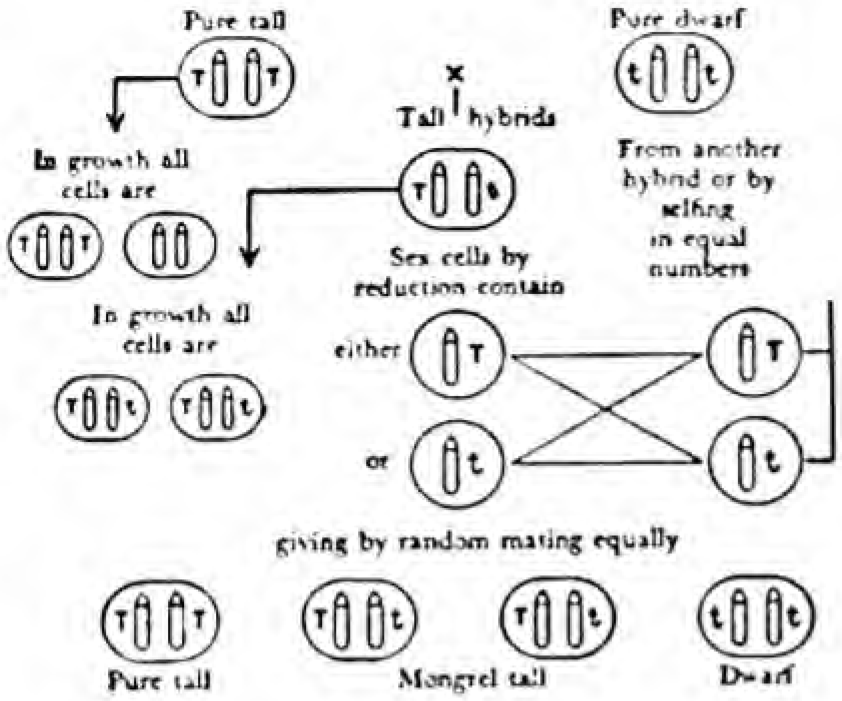
It was not until many years later that the biology of reproduction by means of the sex cells was clearly understood, in fact some 50 years passed before Mendel's theory of heredity found its counterpart in the observations of cytologists, that is of people who examine cells under the microscope. Reference to the colour plate, and to page 11, will make it clear that cells contain chromosomes and that when they divide to form new body tissue, the cells do so in such a way that the chromosomes of the resulting daughter cells are equal in number to, and are of the same sort as those of its mother cell. This is achieved by each chromosome in vegetative cell division dividing exactly along its length into two half chromosomes. One half goes into each daughter cell. After division is completed each half chromosome grows again into a full chromosome in preparation for the next cell division. In this way a body is grown in which all the cells have the number of chromosomes distinctive of the species. Each type of chromosome for the species is represented in every cell of the body, and represented twice over, (i.e. is one of a pair) since one chromosome of each pair is derived from the male and the other from the female parent. The chromosomes seem to disappear when cells are not dividing, but they always reappear in the correct number and of the right type at every subsequent cell division.

When sex cells are formed a reducing division occurs. Here because of a close association at first developed between the members of each pair of similar chromosomes (called homologues or bivalents) and a subsequent separation, each going into a *different* daughter cell, cells are produced with only half the original number of chromosomes (see colour plate). However, one chromosome of each of the types will be present in every sex cell. We have here an observable process of chromosome segregation or separation that could be the basis of Mendel's segregation of hereditary characters. This will be so if the units of inheritance, known as genes, happen to be set out along the length of each chromosome like beads on a string. The observation of certain giant chromosomes in



insects suggests that this may well be the case, as they show distinct cross-wise banding. As will be seen later, these bands also appear to correspond with the known hereditary make-up. If this interpretation is right, then in a hybrid the genes for alternative versions of the characteristic in question will be situated in identical positions on the mother-derived and father-derived chromosomes of the chromosome pairs.

We may therefore show our tall and dwarf cross as follows:



The Laws of Heredity

Mendel's first law of heredity was, as we have seen, the *Law of Segregation.* This says that in a hybrid the units for contrasting states of a characteristic (e.g. tallness/dwarfness) separate (segregate) equally as between two different sets of sex cells (e.g. those containing the tallness factor and those containing the dwarfness factor). Since these sex cells combine at random in forming the next generation the contrasting forms of the characteristic are themselves found to separate out amongst the progeny in certain simple ratios. This law has been found to hold for an enormous number of different cross breedings in a wide range of creatures, both plant and animal.

Mendel went on to state a second law which is now known to be true only under certain conditions. It is however a law we must first learn if we are to understand the reasons why it is not always obeyed. It is called the *Law of Independent Segregation* and states that where we study the simultaneous inheritance of two different characteristics, segregation or assortment of one of these proceeds independently of the segregation of the other. We see it in garden peas when differences of height of plant and of kind of seed are transmitted in the same cross.

Two-factor inheritance.

Pure bred Tall pea with round seeds × Dwarf pea with wrinkled seeds — Pure bred

All F1 are Tall and round-seeded (i.e. round seededness is dominant like) tallness

Self pollination

9 Tall round seeded — 3 Tall wrinkled seeded — 3 Dwarf round seeded — 1 Dwarf wrinkled seeded — F_2 ratio of types

Note there are: 12 Tall to 4 Dwarf

12 Round — 4 wrinkled

Several facts must be noticed about the four sorts of F2 plant. Consider the segregation of tallness/dwarfness.

There are:

$$\begin{array}{ccc} 9+3 & \text{to} & 3+1 \\ \text{tall plants} & & \text{dwarf plants} \end{array}$$
$$= 12 \text{ to } 4 \text{ or } 3 \text{ to } 1$$

which is what we obtained when making a simple cross of tall × dwarf plants! Similarly for the segragation of round/wrinkled the ratio is also

12 to 4 or 3 to 1 again!

It is obvious therefore that tallness/dwarfness and roundness/wrinkleness have *both* segregated in a normal fashion, and that both have done so quite without affecting each other (i.e. *independently*).

It is easy to see in this cross that the F1 individuals, whilst only displaying the dominant characteristics of tallness and round-seededness, must be of constitution Tt : Rr (where R = round seed factor and r = wrinkled), because they are the product of unlike, but pure-bred parents. What, however, happens when plants of this sort form ovules and pollen? Well, we have seen for tallness/dwarfness that sex cells will be produced in such a way that

50% contain T
and
50% contain t.

It will also happen for round/wrinkled seededness that sex cells must be produced so that

50% contain R
and
50% contain r

Now we have seen from the breeding results that each of these segregations proceeds independently of the other. *Therefore,* since a factor for height and factor for seededness must both be in each sex cell, half of the T-containing sex cells must also contain R and the other half r. Likewise for the t-containing ones, half will also contain R and the other half r. So *there will be four sorts of gametes,* those containing TR, Tr, tR, tr; and *each kind will occur equally abundantly.* Since this must be as true for ovules as for pollen, we can find out the probable combinations in producing the next generation (F2) by a device similar to that used to work out the fixtures between the teams of a football league. It is called the chessboard method.

Chessboard shows all possible unions between — Four equally abundant types of pollen grain (columns) — Four equally abundant types of ovule (rows)

	TR	Tr	tR	tr
TR	TT RR Tall Round	TT Rr Tall Round	Tt RR Tall Round	Tt Rr Tall Round
Tr	TT Rr Tall Round	TT rr Tall wrinkled	Tt Rr Tall Round	Tt rr Tall wrinkled
tR	Tt RR Tall Round	Tt Rr Tall Round	tt RR dwarf Round	tt Rr dwarf Round
tr	Tt Rr Tall Round	Tt rr Tall wrinkled	tt Rr dwarf Round	tt rr dwarf wrinkled

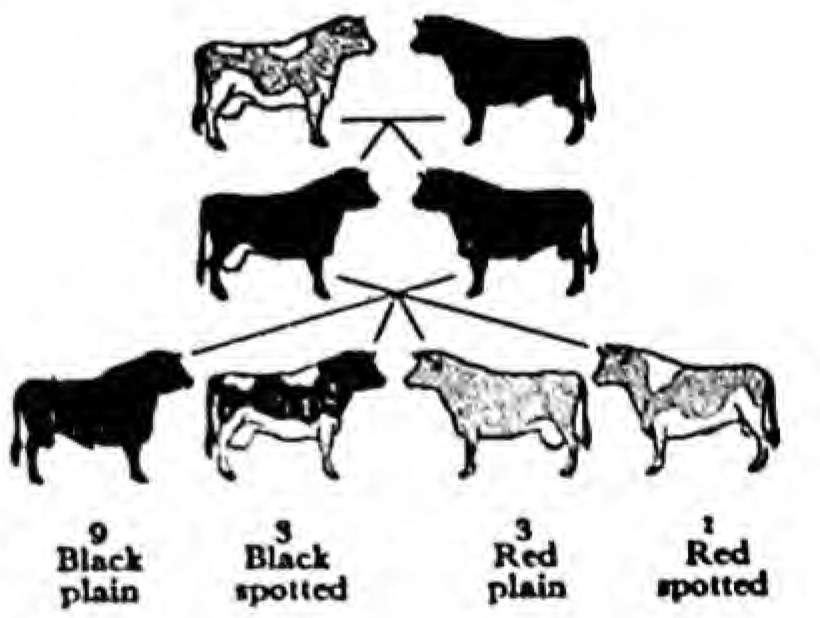
A little totting up will show that the final result for large numbers of matings will approach the ratio

9	:	3	:	3	:	1
tall round		tall wrinkled		dwarf round		dwarf wrinkled

We must further notice that the chessboard shows that of the 9 tall round only one ninth are pure breeding (i.e. TT RR); and of both the tall wrinkled and the dwarf round only one third are pure breeding. These last two types are novelties—not having appeared in these crossings before—and by selection they can be secured in the pure breeding farms TTrr and ttRR. This shows how hybridisation can occasionally produce new types or varieties which are at once "fixed", as the saying goes (that is are true breeding when mated with others of their own sort). You will also notice that all the pure-breeding types lie on the diagonal of the chessboard. This is where each team in the football league meets itself!

A similar example for the animal world appears in colour on p. 160. Drosophila is the name of a tiny fly that lives on ripening fruit. In the wild state it is a winged fly with striped body. In cultivation states of near winglessness (vestigial) and of black (ebony) body are known. These are due to recessive factors (or genes). Our example shows the result of crossing pure breeding vestigial striped × pure breeding winged ebony body.

Note the 9:3:3:1 ratio in the F_2 generation. You will also be interested in the pure breeding novelty—the near wingless ebony. A similar example is the cattle cross shown here.



9 Black plain — 3 Black spotted — 3 Red plain — 1 Red spotted

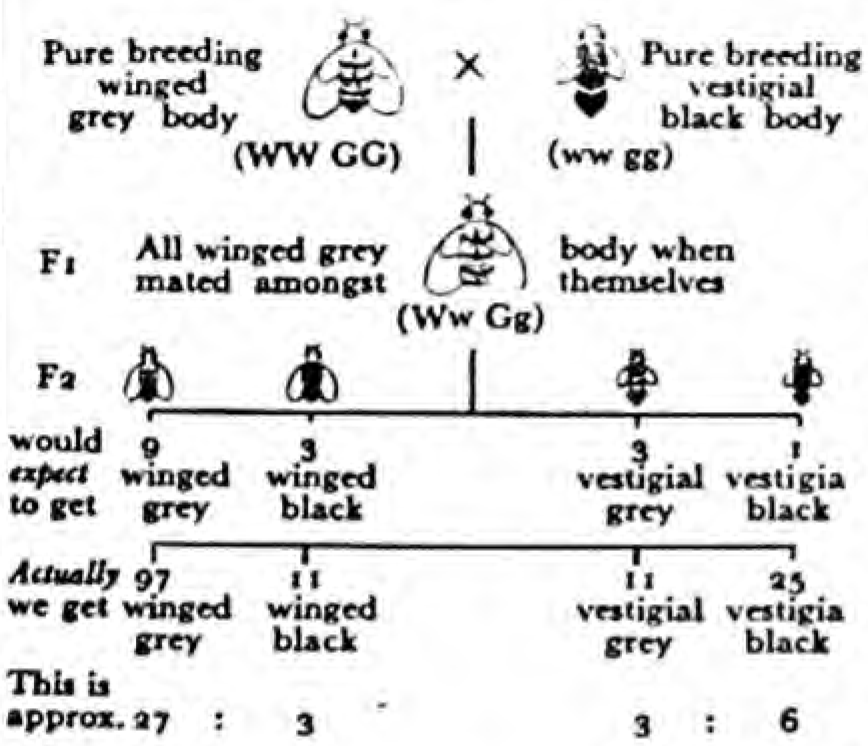
Your turn to have a go.

Now try and see if you can work out for yourself why the cattle cross shown on page 160 gives the ratio that is got in the F2. You will easily be able to see that the dominant aspects of the three characteristics that are being transmitted are hornlessness, white face and blackcoat. Why? The rest follows on just as in previous examples. But this time there will be eight kinds of sex cells to combine together in your chessboard, which will therefore need to have 64 squares!

When you have made your own attempt you can check it with the answer shown on page 167.

The Linkage of Characteristics in Transmission

We have said that Mendel's Law of Independent Segregation is not always obeyed. Here is an example. In Drosophila black body (gg) is the result of the action of a *different* recessive gene to the ebony one that was crossed previously. It is alternative to *grey* body (GG). Let us make the cross shown here:



It can be seen that in this cross

$$\text{winged/vestigial}\ \left(\frac{97+11}{11+25}=\frac{108}{36}=\frac{3}{1}\right)$$

$$\text{and grey/black body}\ \left(\frac{97+11}{11+25}=\frac{3}{1}\right)$$

are segregating as expected from Mendel's First Law, but since the ratio of 9 : 3 : 3 : 1 is not obtained they are obviously not segregating independently. You will notice that the types that occur too frequently are winged, grey body and vestigial, black body. Do you notice that these are the associations which existed in the grandparents (P1)? Somehow winged and grey body have stuck together in later generations more often than they have gone apart. This is also the case for vestigial and black body. Such behaviour is called linkage. But note that this linkage is *sometimes* broken (i.e. it is partial), otherwise we would in the F2 get no flies showing winged, black body, or vestigial, grey. These two sorts are called the "cross over" types because in them the original linkage has been broken. All very puzzling? Well, yes and no! If we suppose that the sex cells from the F1 that carry the cross-over combination of genes are only formed in the ration of 1 : 5 (instead of 1 : 1) to those carrying the linked combination then we shall get a chessboard like this:

Types and proportions of sex cells formed by F1	5 WG	1 Wg (Cross-over type sex cells)	1 wG (Cross-over type sex cells)	5 wg
5 WG	25 WW GG winged grey	5 WW Gg winged grey	5 Ww GG winged grey	25 Ww Gg winged grey
1 Wg (Cross over type of sex cell)	5 WW Gg winged grey	1 WW gg winged black	1 Ww Gg winged grey	5 Ww gg winged black
1 wG (Cross over type of sex cell)	5 Ww GG winged grey	1 Ww Gg winged grey	1 ww GG vestigial grey	5 ww Gg vestigial grey
5 wg	25 Ww Gg winged grey	5 Ww gg winged black	5 ww Gg vestigial grey	25 ww gg vestigial black

By random mating of the sex cells we would get:

Winged grey	$25+5+5+25+5+1+5+1+25=97$
Winged black	$1+5+5=11$
Vestigial grey	$1+5+5=11$
Vestigial black	$25=25$

This is the ratio that was obtained in the experiment.

The exact proportion of cross-over sex cells can easily be spotted by crossing an F1 female with a pure-breeding male that has both the recessive characteristics. Thus:

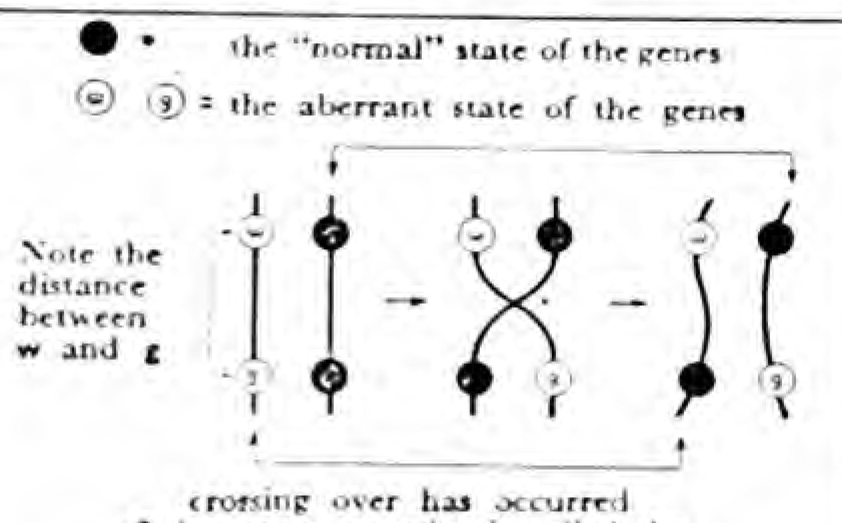
F1 hybrid winged grey female (Ww Gg)	×	Pure-breeding vestigial black male (ww gg)

The pure-breeding fly can *only* produce sex cells containing w and g. The hybrid will produce the usual four types, thus:

Ratio of sex cell types from F1 hybrid	Sex cells from pure-bred male all wg	Actual ratio in F2	Ratio if segregation had been independent
5 WG	5 Ww Gg winged grey	5	1
1 Wg	1 Ww gg winged black	1	1
1 wG	1 ww Gg vestigial grey	1	1
5 wg	5 ww gg vestigial black	5	1

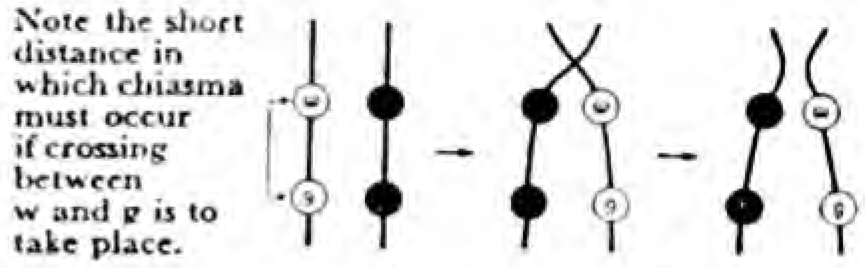
Thus, this being a simpler cross than the interbreeding of the F2, the ratio for the cross-over to non-cross-over sex cells is seen to be the same as the ratio between the four kinds of progeny.

It now remains to find the mechanical basis for this behaviour. If linkage between two traits were absolute we could suppose that the genes controlling them were situated in the same chromosome. But how can this explain a partial linkage such as we have discovered? The answer comes from the observation by cytologists of chromosomes when they are dividing in a reducing division. The chromosomes that make up any pair can then be seen to wrap themselves round each other in a spiral. Whilst in this state they break across their length and exchange portions as shown in the colour plate on p. 160. It is this exchange of substance that keeps them held together. When



crossing over has occurred
* the crossover point is called the chiasma

Crossing over between ⓦ and ⓖ is more likely to occur if their relationship is as above than if it is as below.



In this instance although a chiasma has formed there will be no crossing over between ⓦ and ⓖ i.e. they are still in the same chromosome.

they separate, because of this segment interchange, they are not quite the same chromosomes that commenced to pair. The point of breaking and interchange is called the cross-over. *If* it occurs between the positions of the linked genes we happen to be studying, these will be divorced from one another and cross-over sex cells will be the result. If the interchange does not occur between the genes in question then cross-over sex cells will not be produced. It is evident that crossing-over will in general be least likely to occur if the genes in question are close together in the chromosome, and most likely if they are far apart in the chromosome. In fact the percentages of cross-overs in matings of this kind have been used to calculate the distance of particular genes from one end of the chromosome in which they are carried! On page 163 you see such a "cross-over" map for some of the genes known to be carried in what is called the first chromosome pair of Drosophila.

It happens that in the glands of Drosophila which produce its saliva (or spit) the chromosomes are extra large in size and their construction can very clearly be seen under the microscope. Extremely careful examination of these chromosomes in differing varieties of the fruit fly has made possible identification in the chromosomes of the sites for the genes of characteristics already identified by breeding. In the figure, lines join the gene sites in the chromosome to the gene positions as calculated on the cross-over map. That is the extent to which many traits can be linked up to the make-up of a creature's chromosomes!

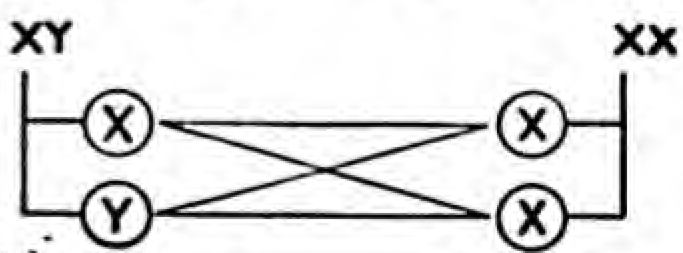
The Inheritance of Sex

This provides another straightforward example of segregation—but this time of chromosomes rather than of particular genes. In the fly Drosophila, as in man and the mammals generally, the cells of males show a chromosome shortage. Male Drosophila have the fourth pair of chromosomes unequal in size, a smaller one X and a larger one Y. On the other hand the cells of females have the fourth pair made up of two similar X-type chromosomes.

When a female Drosophila forms eggs by a reduction division all her eggs must contain an X chromosome—i.e., XX→ ⓧ + ⓧ. Not so with males. Half their sperm cells will contain an X chromosome and the remaining half a Y chromosome—i.e.,

$$XY \rightarrow ⓧ + ⓨ.$$

The cross male Drosophila × female Drosophila is therefore like the back cross of Mendel's hybrid pea with the recessive parent.



The result is:

$$\underbrace{XX\ XX}_{\text{2 females}} \qquad \underbrace{XY\ XY}_{\text{2 males}}$$

or a ratio of 1 : 1 between the sexes

It is now clear why in populations of animals the sexes normally remain more or less equal in numbers. Once again we have a correspondence between a ratio obtained in breeding tests and a visible difference in the chromosome make-up of the individual produced. It will be seen that in cases of this sort it is the sperm from the male parent which determines the sex of the next generation.

Drosophila. Male.

Vegetative (mitotic) division to form fresh body cells in growth and repair.

(= ordinary reproduction by budding)

Note: The paired chromosomes as from father and mother are shown bracketed.

Note: Female flies have XX condition.

from father

from mother

Stage 1.
Early stage of vegetative cell division.

Note: This behaviour would seem to *suggest* that the chromosomes carry *along their length* (like beads on a necklace) units that control the hereditary likeness between the original cell and its products. (Cuttings from any part of a plant give rise to a plant exactly like the original.)

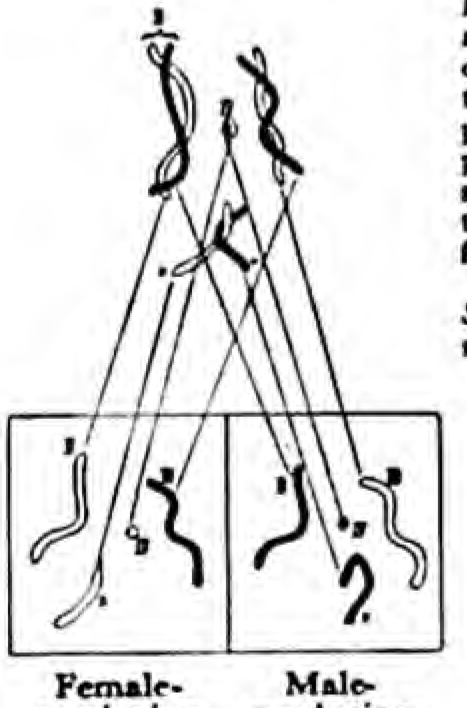
+ another cell *exactly* like this one.

Stage 2.
Division of the chromosomes longitudinally is followed by separation between resulting "half chromosomes" into different "daughter" cells, whose chromosomes will be exactly alike.

Stage 3.
The result of chromosome separation is two cells (one shown) *exactly* like the original cell.

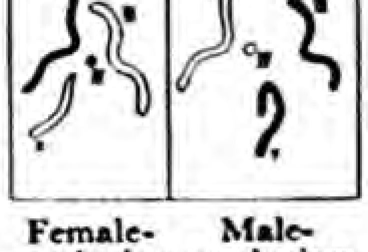
Reducing division to form *sex cells* (= first phase of sex reproduction).

Stage 1
Chromosomes appear already paired.



Notice that the XY pair are only able to pair up over a *very* small sector of their length. In other pairs coiling can take place over almost any sector of the chromosomes, though not with equal freedom.

Stage 2. Members of pairs separate.



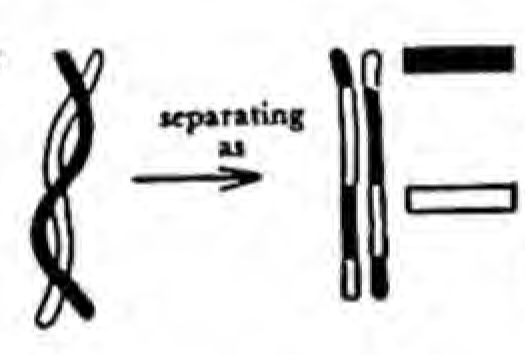
Female-producing sperm. Male-producing sperm.

Female-producing sperm. Male-producing sperm.

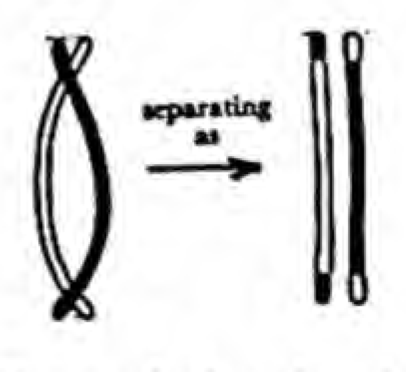
Stage 3. Resulting Sperm Cells.
Male-determining and female-determining sperm must be formed in equal numbers since they result from the separation of X and Y chromosomes. Various combinations are possible.

1. The procedure in reduction division results from the development of coiling as between members of chromosome pairs.
2. It results in daughter cells with half the original chromosome number (this is restored at fertilisation).
3. Since mother-derived and father-derived chromosomes must go into different daughter cells the parent must dismantle its hereditary constitution at sex reproduction. The sex cells cannot, therefore, have a hybrid condition.
4. Thus unless the parent is purebred its sex cells will be unlike as among themselves, and each will be able to convey only half of the set-up that made the parent to be a hybrid.
5. Since the process of chromosome separation into the daughter cells is a random one the variety of sex-cell types (from the one parent) is still further increased, the only condition that must be fulfilled being that the two members of the same pair cannot go into the same sex cells Thus numerous permutations are possible for the chromosomes of these cells (a. between mother-derived and father-derived chromosomes).
6. This variability is again further increased by the fact that when chromosomes pair by coiling they commonly break at the point of crossing and come out of the pairing differently constituted from the condition at entry. This, too, can happen in a variety of ways since coiling and crossing-over can usually occur at a range of different places along the length of the chromosomes. The following diagrams illustrate the point:

Pairing

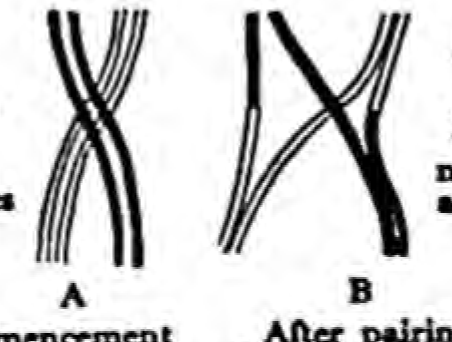


Pairing



Note: The real situation is even more complex than shown here, since the crossing over is really between half chromosomes—the so-called chromatids. This can actually be seen in good preparations and has been dissected out in living cells using micromanipulation.

4 chromatids = 2 chromosomes



Note: The X cross-over effect whence the name for it of a chiasma link

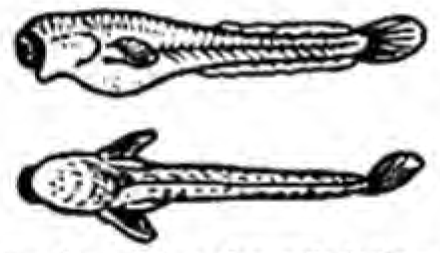
A
Commencement of chromosome pairing.

B
After pairing, showing the basis of the link-up.

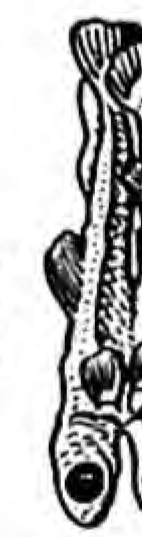
The Influence of Environment

When a creature starts life as a result of the union of egg and sperm, its heredity, received at random from each of its parents, is no more than a collection of possibilities. These have to be worked out (or frustrated) in the course of growth and development. At fertilisation the creature is not male or female, though (as we have seen) it *is* potentially male or potentially female. Likewise for the other inherited differences. Accidents may happen in the course of grow- ing up, and deviation from the appointed path may occur, heredity notwithstanding.

The extent to which environment, or nurture, can influence heredity varies from case to case. We can do little by feeding, exercise or thought to change our eye colour, though slight changes may accompany ill-health. On the other hand much can be done from without to change hair colour, if its inherited character is unacceptable! Heredity is at work in both cases. In one of them it is more readily modified by outside influence than in the other. An extreme case is the fish Fundulus where young fish treated suitably by changing the salt balance of the water can, with an heredity for developing two eyes (as revealed by raising half their number under normal conditions), be made to develop only one eye! A similar experiment can produce one-eyed frog tadpoles from eggs of normal heredity for two eyes.



In Fundulus the salt balance of the surroundings can influence eye development, and oxygen shortage can produce Siamese twins.



Another example that occurs naturally is in cattle. If a cow has twins of opposite sex the one that should, by virtue of its heredity, have been born a female will develop as an abnormal "free martin" because of influences coming from the male twin, which developes normally.

Without heredity there can be no beginning, without environment there can be no development! Thus we see that the mature individual is not the product of

heredity *v.* environment

but of

heredity + environment

To understand the relative importance of heredity and environment we need only to remember that a farmer would never waste good pasture on wild-type cattle, nor would he toil in cultivation of the wild carrot or the wild oat. If he did then his

most strenuous efforts would go unrewarded. This is because the best possible surroundings cannot overrule unsuitable heredity. But equally, when by long attention to breeding and selection, the husbandman has good hereditary strains of cattle, carrots or oats, he will be most foolish if he does not surround them with suitable conditions in which they may do their best. Similar considerations apply in the case of other creatures, including man himself.

Heredity in Man

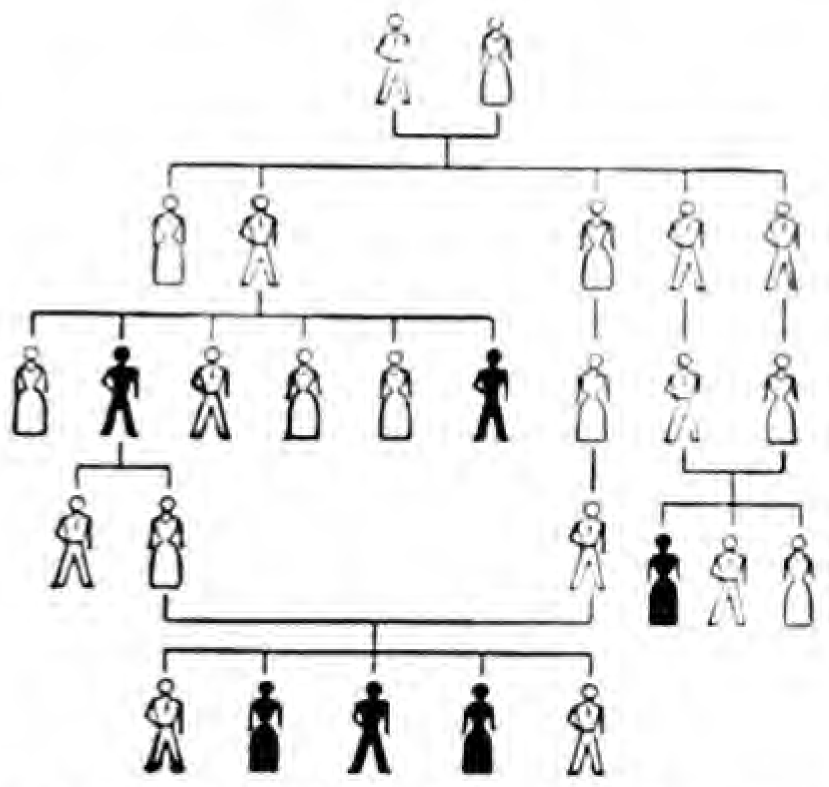
Wherever his heredity can be studied by observing the transmission of an abnormal state of some particular characteristic, as Mendel did for peas, the laws of heredity seem to apply to man just as they do to plants and other animals. But there are many difficulties in the study of human heredity. Man's families are usually small ones, so the test of large numbers has to be made by means of statistical adjustments. His generations are long ones, as he rarely produces children before the age of 14 years, and the family may not be completed until late in life. So the study of man's heredity can advance only slowly. Again, memories are short; few of us know anything definite enough about our grandparents for the human geneticist to rely very much upon past generations as test material for his theories. Lastly, many of the things about man that interest us most—his disposition, his health, his intelligence, his good or bad looks—are complex characteristics difficult to measure and, where hereditary influences have been discovered at work, they have frequently proved to be very complicated in their mode of action.

But the picture for man is not without outline, nor indeed without highlights! As in Drosophila, so in man—males and females consistently differ in their chromosomes. Women have 48 chromosomes ($= 2 \times 23 +$ a sex pair XX), whilst men have $47\frac{1}{2}$ chromosomes ($= 2 + 23 +$ a sex pair XY, the Y chromosome being tiny). Boys and girls are born in nearly equal numbers due to the segregation of X and Y chromosomes into equal numbers of sperm.

Blue eye colour in man is *recessive* to other eye colours. Thus blue-eyed children can in a small proportion of cases be born to two dark-eyed parents. This is where *both* parents happen to be hybrid for their dark eye colour and each carries a recessive gene for blue. In such instances about 1 in 4 of their children may have blue eyes. (Do you remember the two black (hybrid) mice that produced 25% of their offspring as white mice?) We would expect from this that two blue-eyed parents could never have dark-eyed children, and this is normally the case. But because more than one pair of genes can influence eye colour (remember black body in Drosophila can be due to two quite different genes), in *very* rare instances such parents may produce a dark-eyed child.

A state of short fingers in man appears to arise by *interaction* between an abnormal gene and the normal one. Only persons showing the condition can transmit it to the next generation, since the gene always shows its presence in the hybrid state.

The inheritance of another human recessive condition—albinism—is shown in the following figure.



Albinism runs in this family, but not vertically (i.e. from parent to child). Since it is a recessive condition it *may* be conveyed by "normal" carriers. But the condition occurs horizontally (i.e. amongst brothers and sisters) more often than in the general community. There are 3 out of 5 affected in the last generation—which was produced by marriage within the family, which increases the probability that *both* parents will be carriers.

Answer to the cattle cross shown on page 160.

TRI-HYBRID CROSS IN CATTLE

Hornless, plain faced, black × horned, white faced red

F1 is *Hornless, white faced, black. Thus these characteristics are dominant.*

Let H = "hornless" gene. F = "white faced" gene. B = "black coat" gene. The F1 animals thus are Hh, Ff, Bb. With independent segregation such animals must form eight kinds of sex cell as follows:—

	HFB	HFb	HfB	Hfb	hFB	hFb	hfB	hfb
HF B	HH hornless FF white faced BB black	HH hornless FF white faced Bb black	HH hornless Ff white faced BB black	HH hornless Ff white faced Bb black	Hh hornless FF white faced BB black	Hh hornless EF white faced Bb black	Hh hornless Ff white faced Bb black	Hb hornless Ff white faced BB black
HF b	HH hornless FF white faced Bb black	HH hornless FF white faced bb red	HH hornless Ff white faced Bb black	HH hornless Ff white faced bb red	Hh hornless FF white faced Bb black	Hh hornless FF white faced bb red	Hh hornless Ff white faced Bb black	Hb hornless Ff white faced bb red
Hf B	HH hornless Ff white faced BB black	HH hornless Ff white faced Bb black	HH hornless ff plain faced BB black	HH hornless ff plain faced Bb black	Hh hornless Ff white faced BB black	Hh hornless Ff white faced Bb black	Hh hornless ff plain faced BB black	Hb hornless ff plain faced Bb black
Hf b	HH hornless Ff white faced Bb black	HH hornless Ff white faced bb red	HH hornless ff plain faced Bb black	HH hornless ff plain faced bb red	Hh hornless Ff white faced Bb black	Hh hornless Ff white faced bb red	Hh hornless ff plain faced Bb black	Hh hornless ff plain faced bb red
hF B	Hh hornless FF white faced BB black	Hh hornless FF white faced Bb black	Hh hornless Ff white faced BB black	Hh hornless Ff white faced Bb black	hh horned FF white faced BB black	hh horned FF white faced Bb black	hh horned Ff white faced BB black	hh horned Ff white faced Bb black
hF b	Hh hornless FF white faced Bb black	Hh hornless FF white faced bb red	Hh hornless Ff white faced Bb black	Hh hornless Ff white faced bb red	hh horned FF white faced Bb black	hh horned FF white faced bb red	hh horned Ff white faced Bb black	hh horned Ff white faced bb red
hf B	Hh hornless Ff white faced BB black	Hh hornless Ff white faced Bb black	Hh hornless ff plain faced BB black	Hh hornless ff plain faced Bb black	hh horned Ff white faced BB black	hh horned Ff white faced Bb black	hh horned ff plain faced BB black	hh horned ff plain faced Bb black
hf b	Hh hornless Ff white faced Bb black	Hh hornless Ff white faced bb red	Hh hornless ff plain faced Bb black	Hh hornless ff plain faced bb red	hh horned Ff white faced Bb black	hh horned Ff white faced bb red	hh horned ff plain faced Bb black	hh horned ff plain faced bb red

Total result by proportion:

Hornless white faced black	Hornless plain faced black	Horned white faced black	Hornless white faced red	Horned plain faced black	Hornless plain faced red	Horned white faced red	Horned plain faced red
27	9	9	9	3	3	3	1

Note: The dotted cages show how the four types of sex cell for a bi-hybrid cross become eight types when B and b also segregate independently.

Multifactor Inheritance in Man

Those human traits like height, skin, colour and intelligence that are present in varying degrees of intensity (we are not *either* tall *or* short, brilliant *or* dull!) can be considered as due to the existence of inheritance systems in which many pairs of genes act in such a way that their effects add up. (This can be thought of as a special instance of the Hereford cattle cross you worked out for yourself. If A, B and C are dominants and each for effect counts as one, whilst the recessives a, b and c do not count for effect, an individual AA, BB, CC would score 6 on the scale of measurement, the recessive individual aa, bb, cc would score nought, and other conditions would show all possible values from 1 to 5—e.g., Aa, Bb, Cc = 3; Aa, Bb, cc = 2, etc.).

Experimental evidence for this type of inheritance mechanism in man is hard to get, though it exists for some differences of skin colour. For rats an hereditary system of this sort seems to control whatever "intelligence" is measured by skill in solving mazes in the search for food. In the study of human conditions such as height, and whatever "intelligence" is measured by intelligence testing, we have to rely on the less satisfactory method of testing by means of statistical analysis, whence comes some of the controversy about whether these characteristics in man are chiefly result the of good heredity or of good environment.

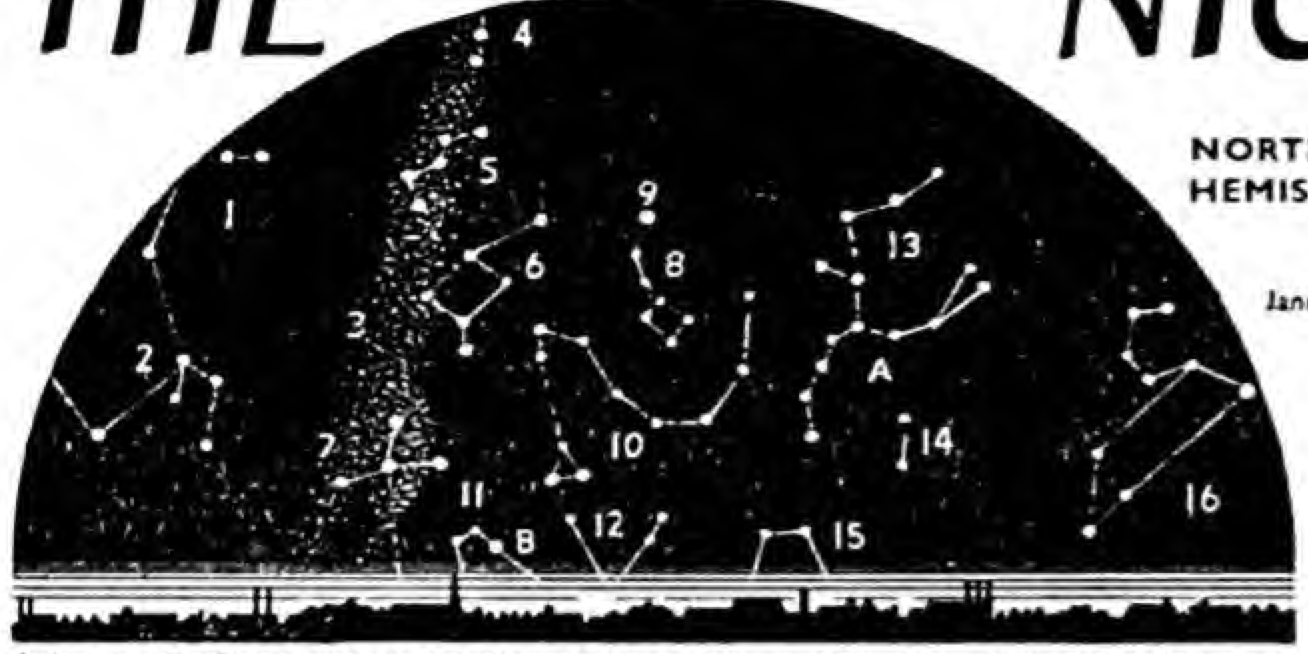
THE NIGHT SKY

NORTHERN HEMISPHERE

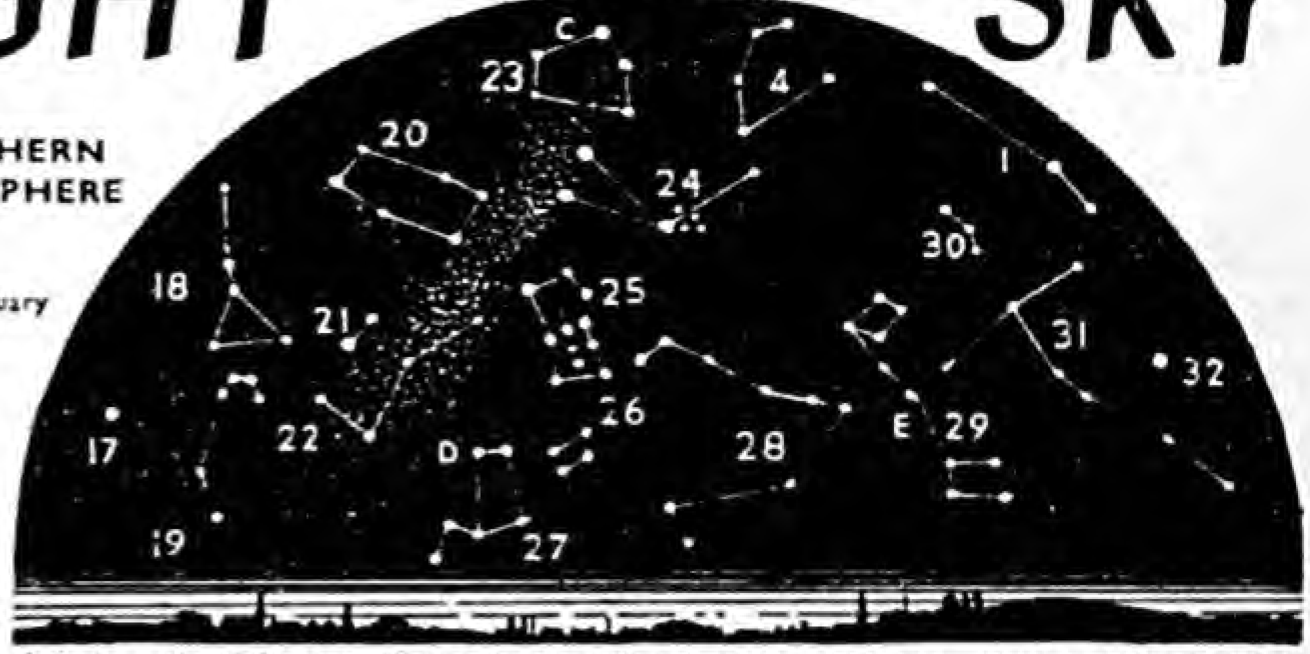
Looking North

Looking South

January

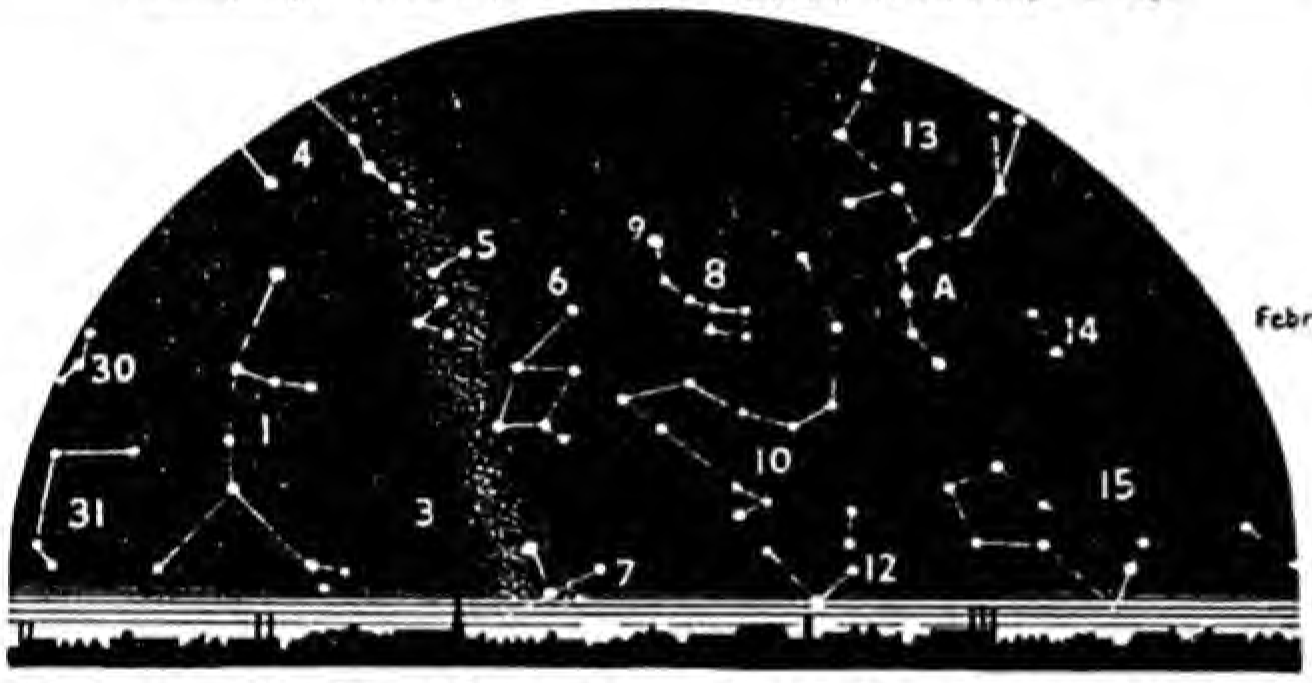


1 Andromeda (Chained Woman) 2 Pegasus (Winged Horse) 3 Via Lactea (Milky Way) 4 Perseus 5 Cassiopea 6 Cepheus 7 Cygnus (Swan) 8 Ursa Minor (Little Bear) 9 Pole Star 10 Draco (Dragon) 11 Lyra (Lyre) 12 Hercules (Giant) 13 Ursa Major (Great Bear) 14 Canes Venatii (Hunting Dogs) 15 Bootes (Herdsman) 16 Leo (Lion) A The Plough B Vega

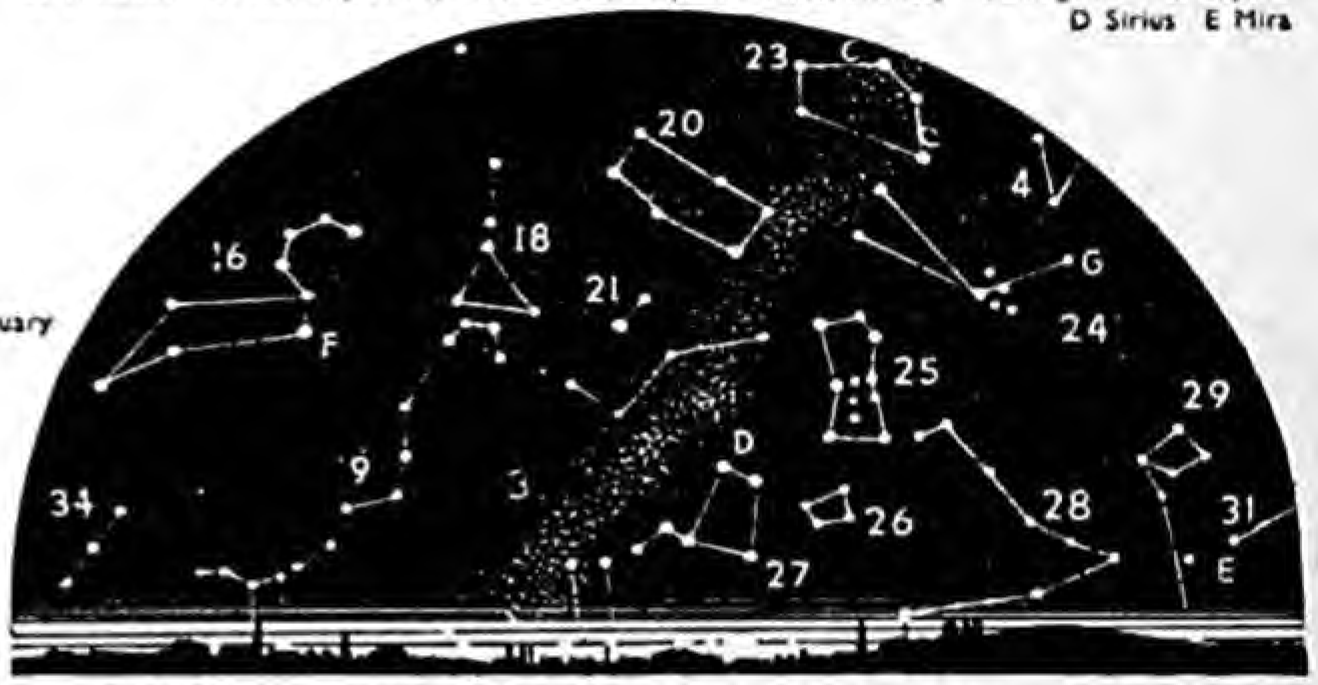


1 Andromeda 4 Perseus 17 Regulus (Part of Leo) 18 Cancer (Crab) 19 Hydra (Water Snake) 20 Gemini (Twins) 21 Canis Minor (Little Dog) 22 Monoceros (Unicorn) 23 Auriga (Charioteer) 24 Taurus (Bull) 25 Orion (Warrior) 26 Lepus (Hare) 27 Canis Major (Great Dog) 28 Eridanus 29 Cetus (Whale) 30 Aries (Ram) 31 Pisces (Fishes) 32 Algenib C Capella D Sirius E Mira

February

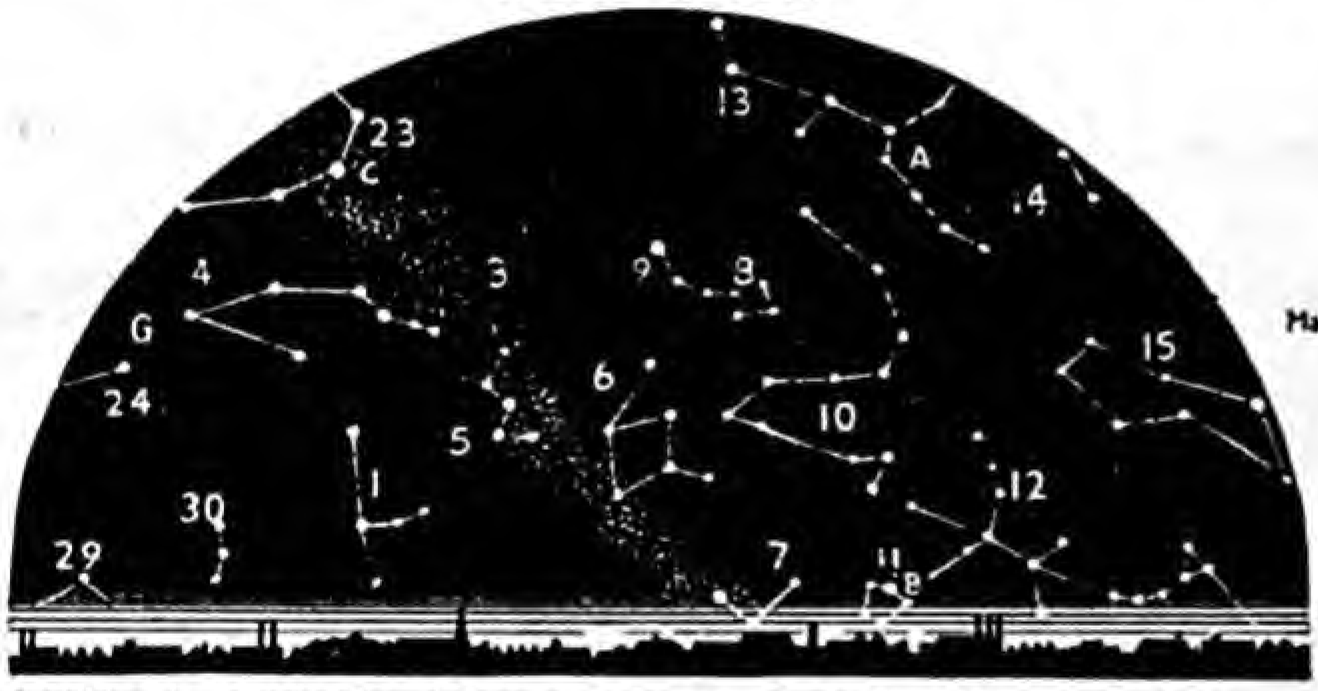


1 Andromeda 3 Milky Way 4 Perseus 5 Cassiopea 6 Cepheus 7 Cygnus 8 Ursa Minor 9 Pole Star 10 Draco 12 Hercules 13 Ursa Major 14 Canes Venatii 15 Bootes 30 Aries 31 Pisces A The Plough

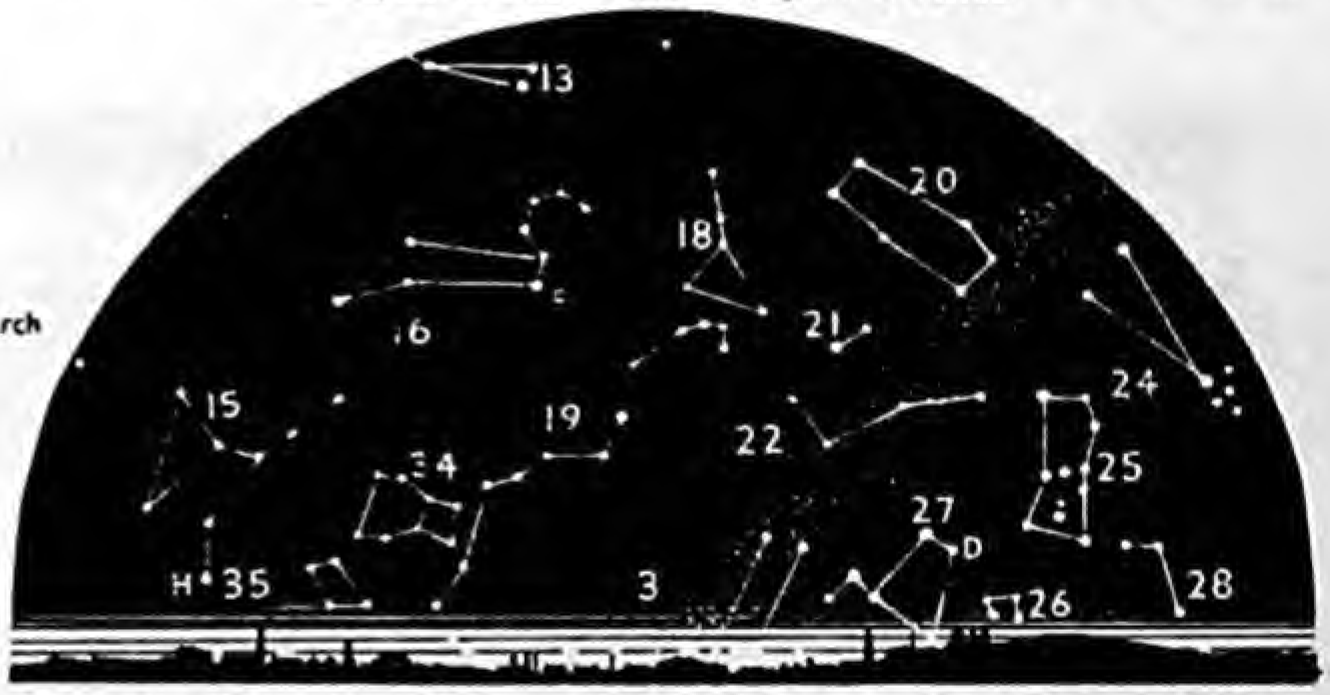


3 Milky Way 4 Perseus 16 Leo 18 Cancer 19 Hydra 20 Gemini 21 Canis Minor 23 Auriga 24 Taurus 25 Orion 26 Lepus 27 Canis Major 28 Eridanus 29 Cetus 31 Pisces 34 Crater (Cup) C Capella D Sirius E Mira F Regulus G Pleiades

March

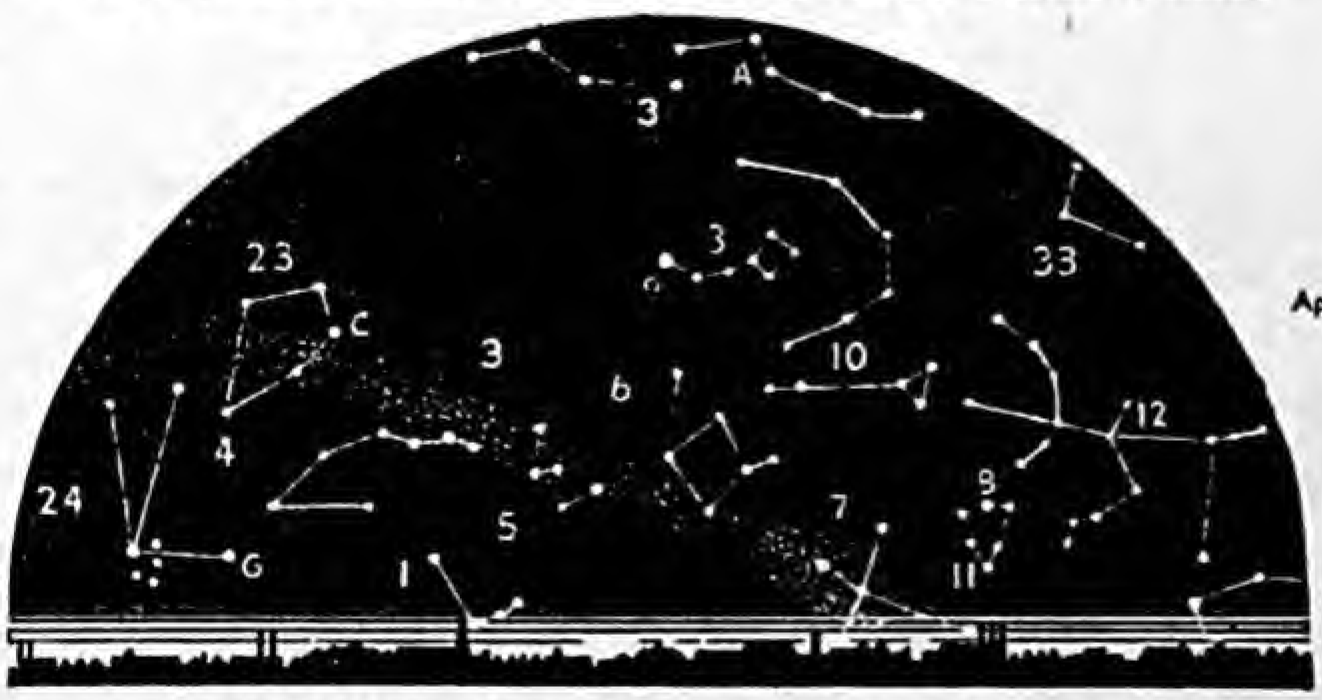


1 Andromeda 3 Milky Way 4 Perseus 5 Cassiopea 6 Cepheus 7 Cygnus 8 Ursa Minor 9 Pole Star 10 Draco 11 Lyra 12 Hercules 13 Ursa Major 14 Cares Venatii 15 Bootes 23 Auriga 24 Taurus 29 Cetus 30 Aries A The Plough B Vega C Capella G Pleiades

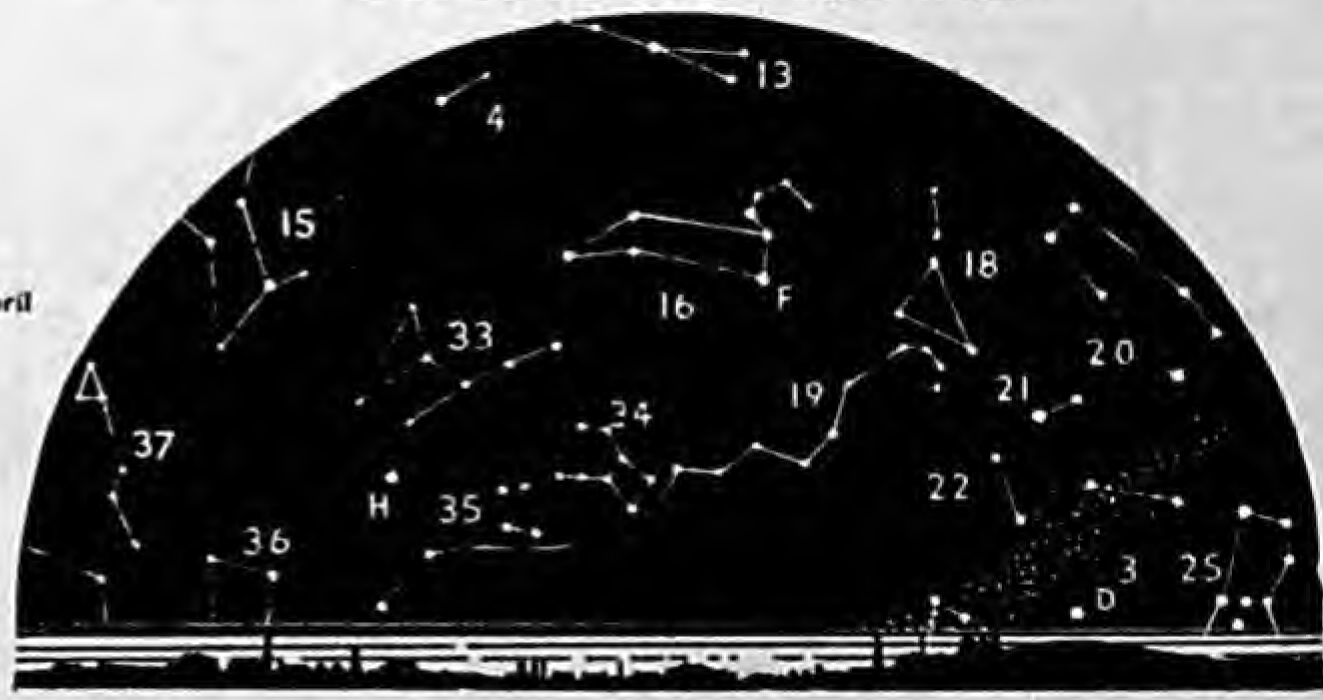


3 Milky Way 13 Ursa Major 15 Bootes 16 Leo 18 Cancer 19 Hydra 20 Gemini 21 Canis Minor 22 Monoceros 24 Taurus 25 Orion 26 Lepus 27 Canis Major 28 Eridanus 34 Crater 35 Corvus (Crow) D Sirius F Regulus H Spica

April



1 Andromeda 3 Milky Way 4 Perseus 5 Cassiopea 6 Cepheus 7 Cygnus 8 Ursa Minor 9 Pole Star 10 Draco 11 Lyra 12 Hercules 13 Ursa Major 23 Auriga 24 Taurus 33 Virgo (Virgin) A The Plough B Vega C Capella G Pleiades



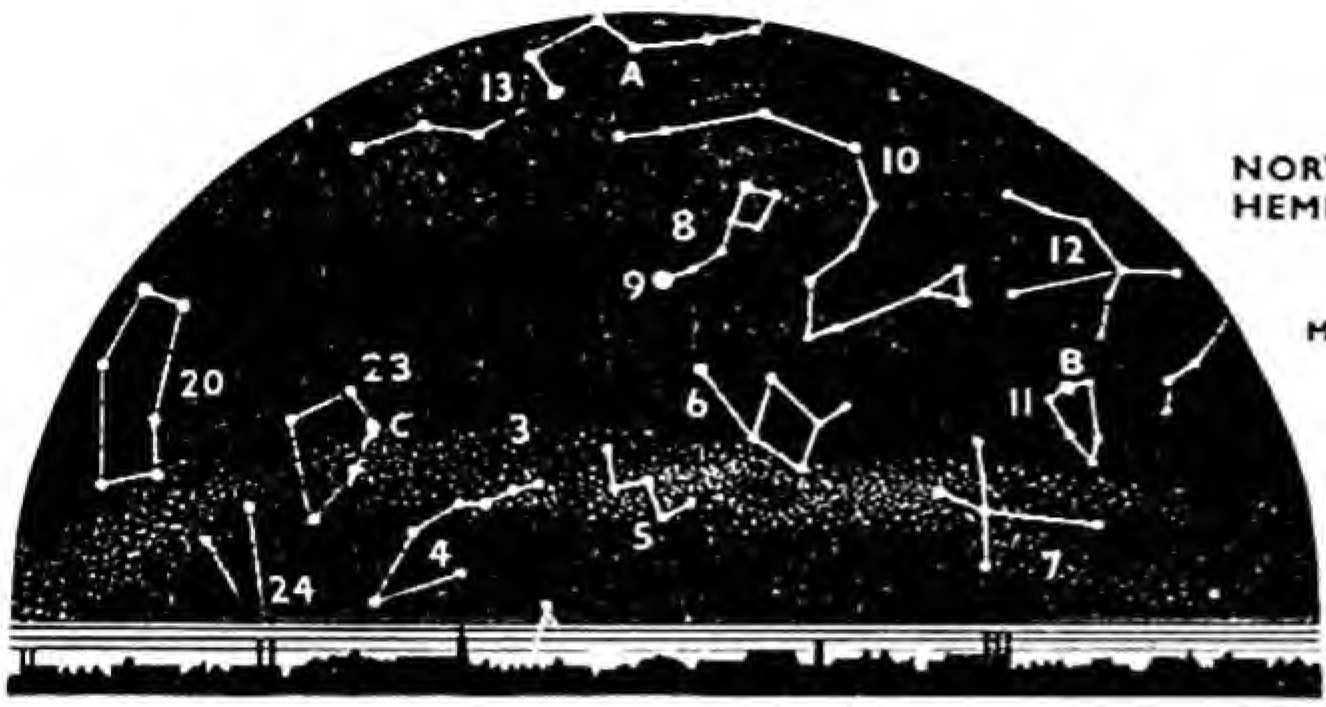
3 Milky Way 13 Ursa Major 14 Canes Venatii 15 Bootes 16 Leo 18 Cancer 19 Hydra 20 Gemini 21 Canis Minor 22 Monoceros 25 Orion 33 Virgo 34 Crater 35 Corvus 36 Libra (Scales) 37 Serpens Caput D Sirius F Regulus H Spica

Looking North

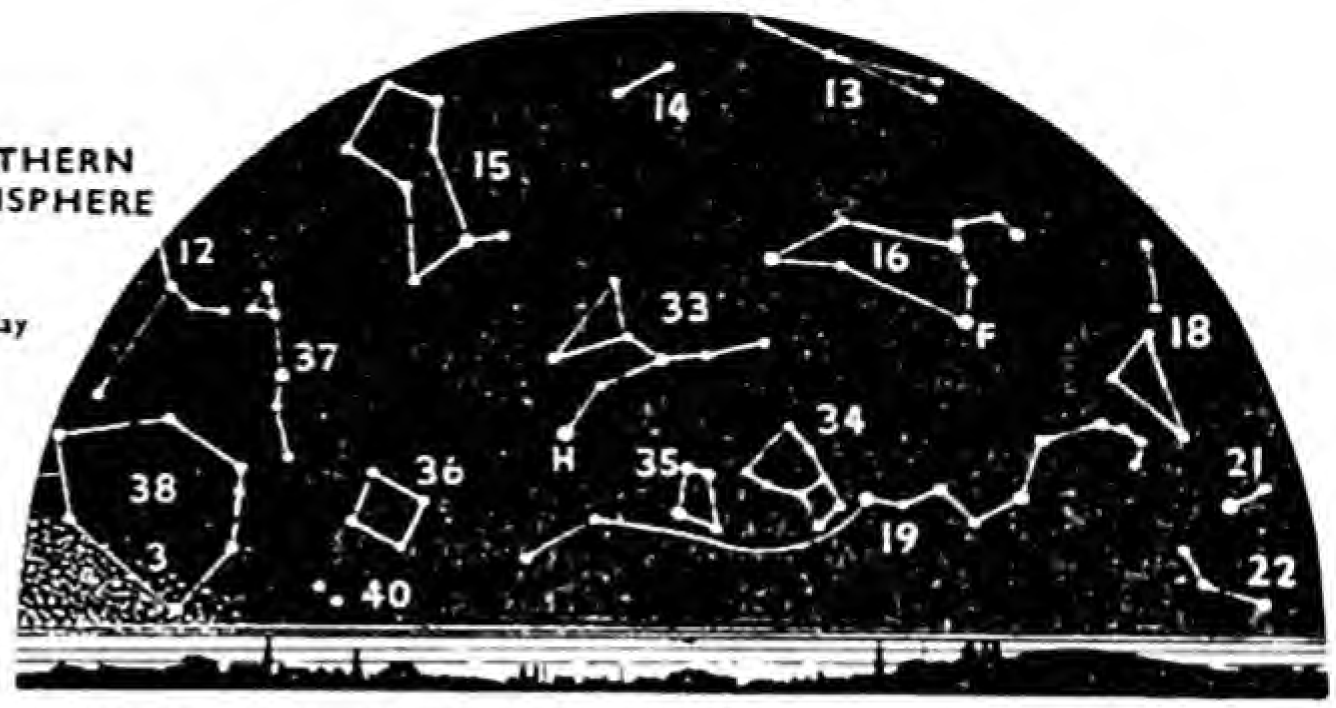
Looking South

NORTHERN HEMISPHERE

May



3 Milky Way 4 Perseus 5 Cassiopea 6 Cepheus 7 Cygnus 8 Ursa Minor 9 Pole Star 10 Draco 11 Lyra 12 Hercules 13 Ursa Major 20 Gemini 23 Auriga 24 Taurus A The Plough B Vega



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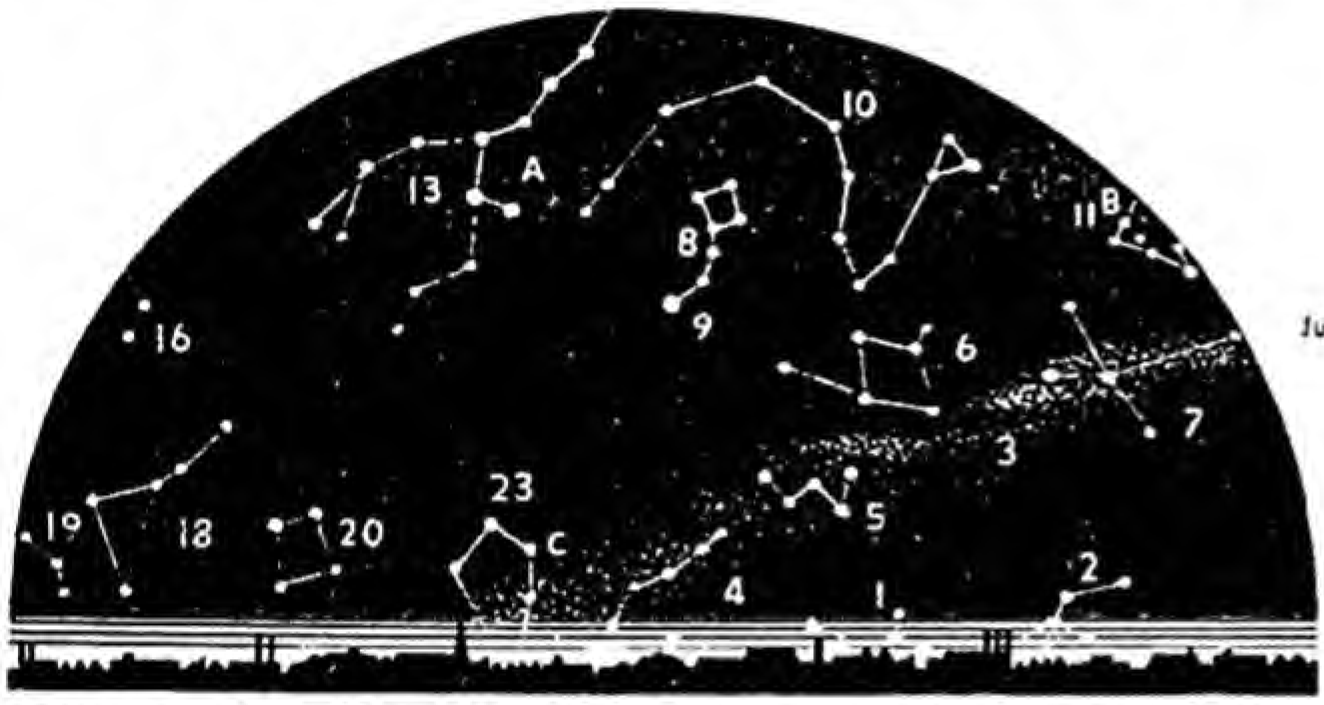
June



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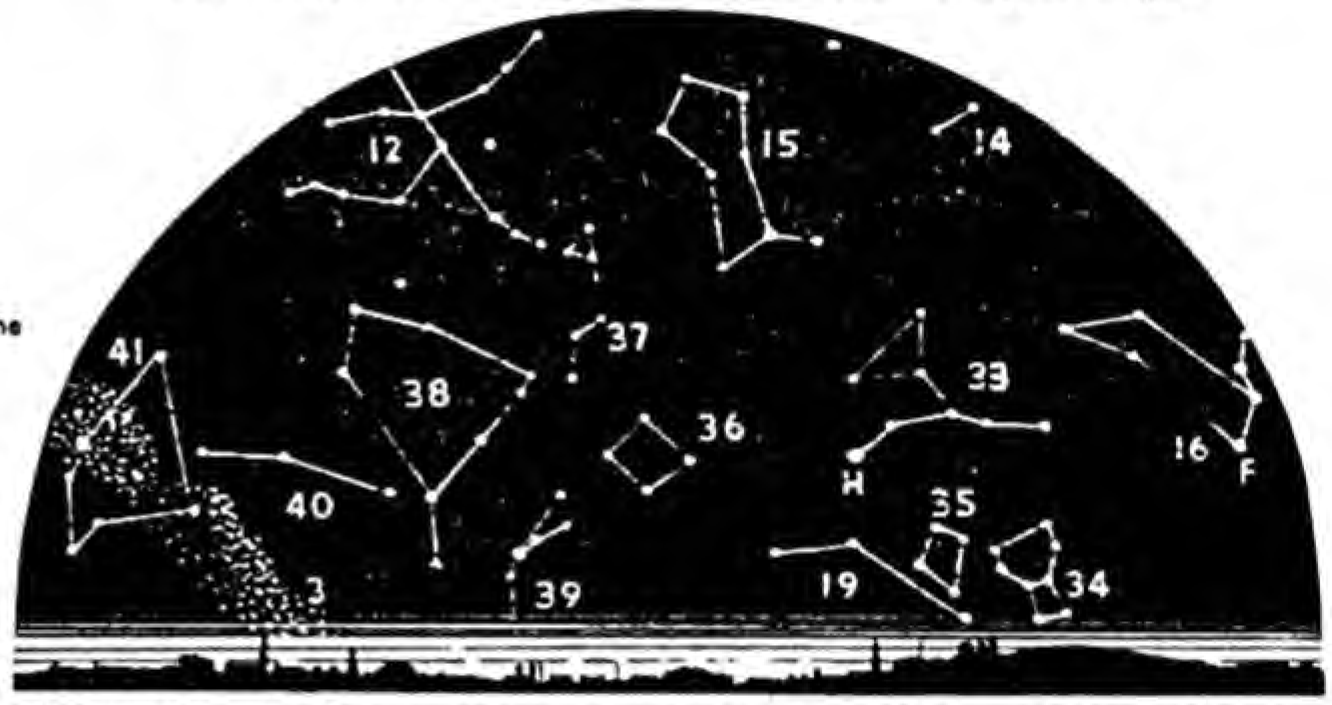

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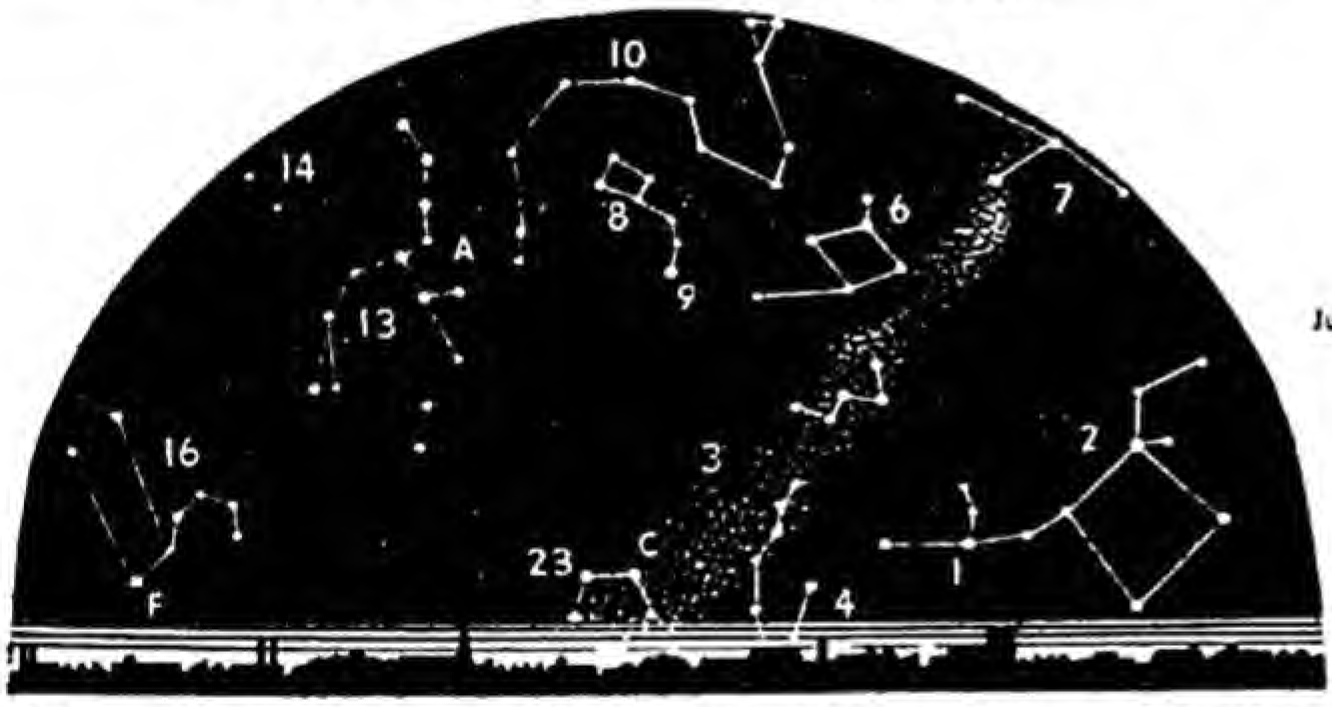
July



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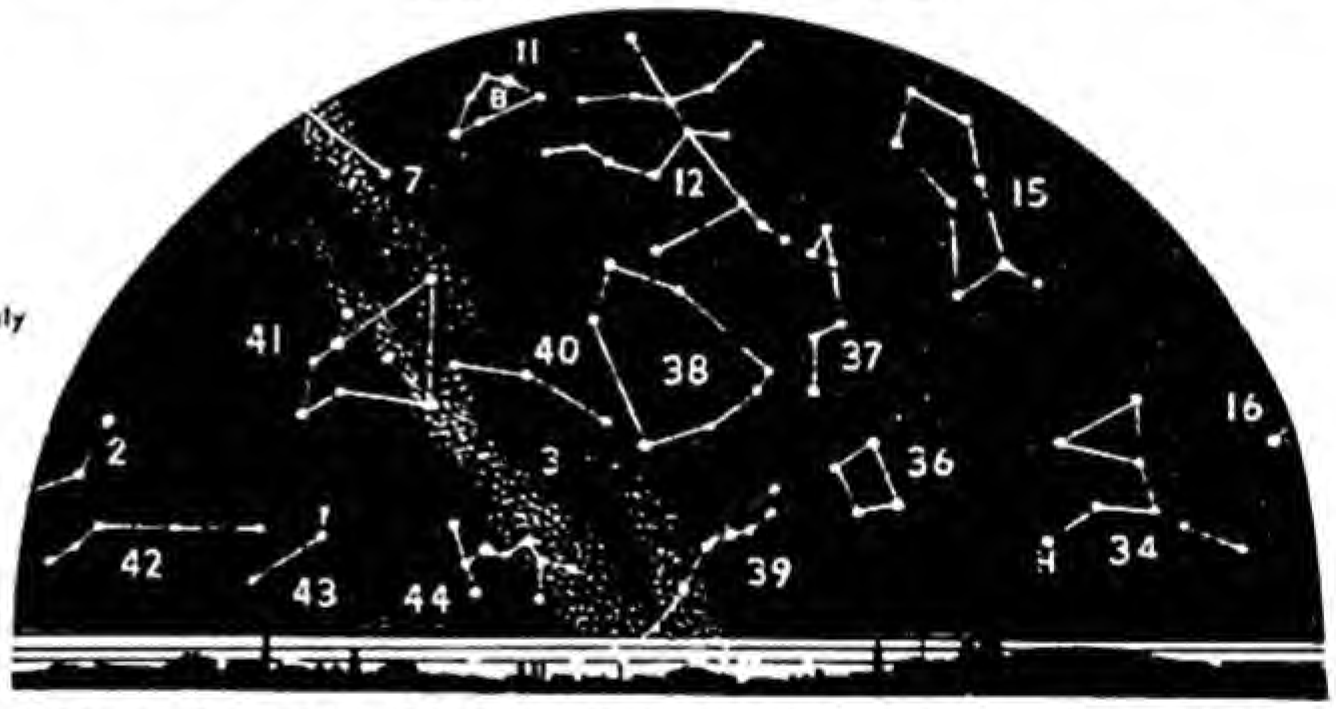

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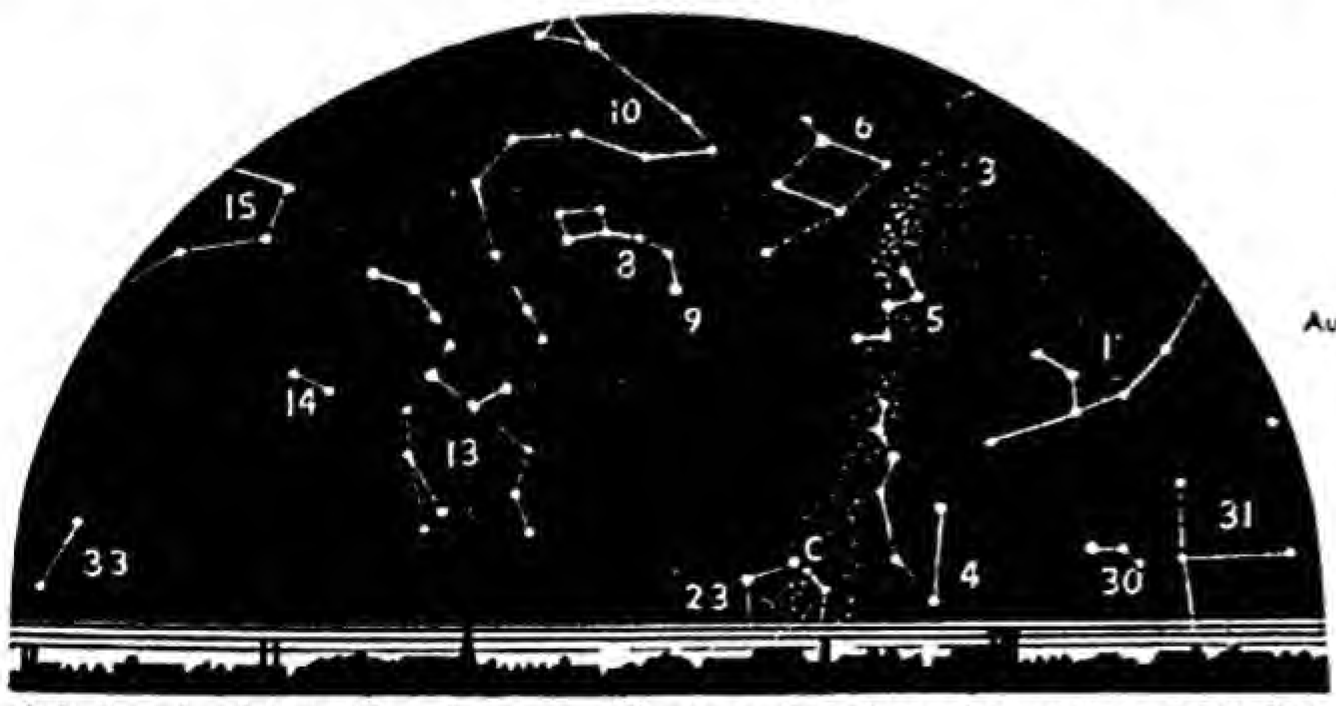
August



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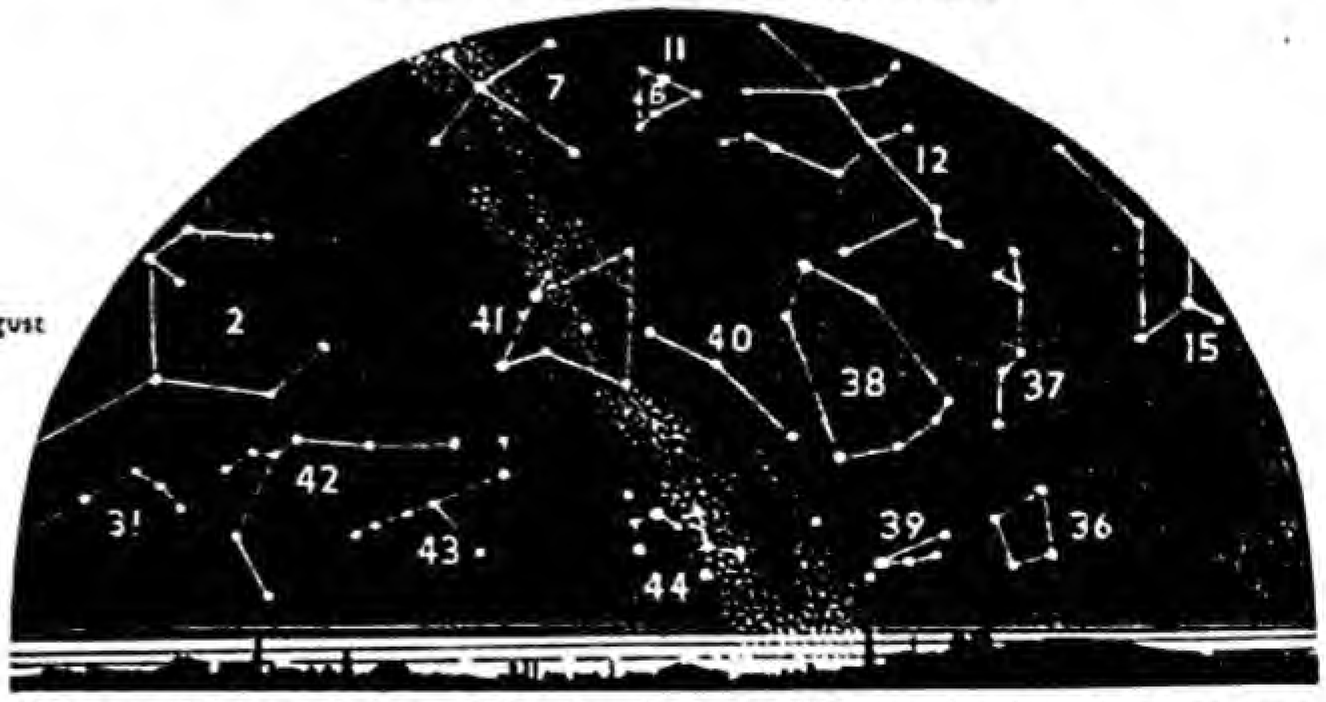

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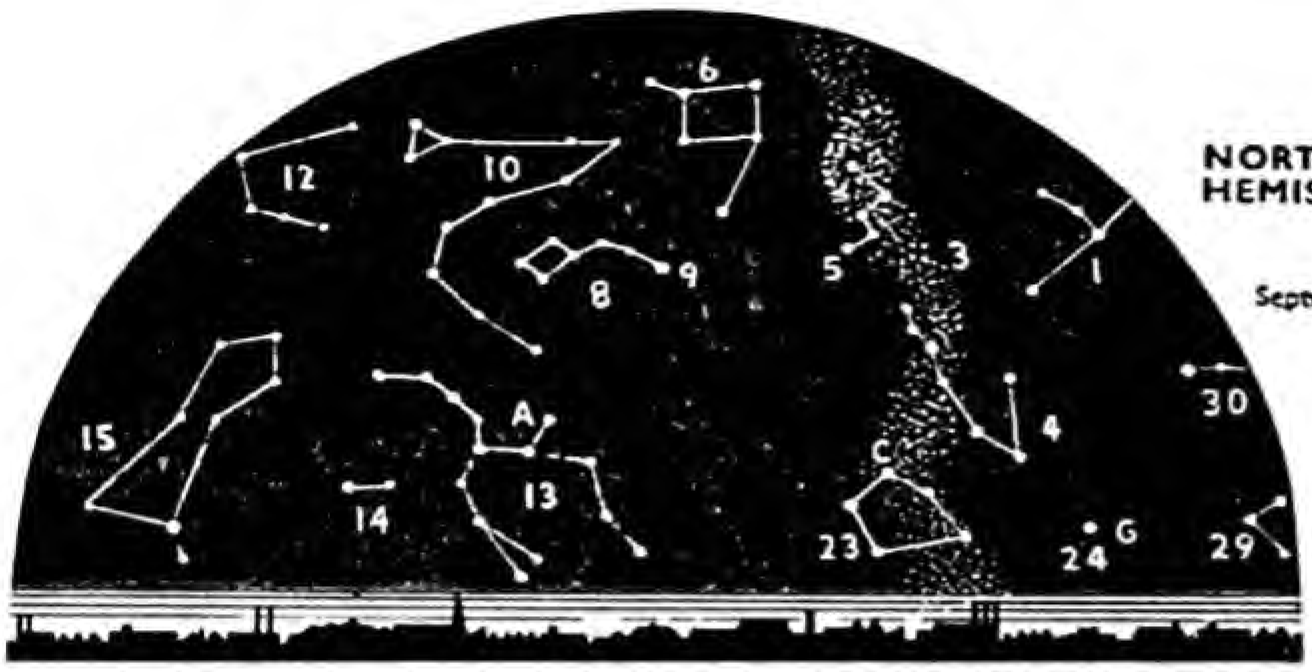
Looking North

Looking South

NORTHERN HEMISPHERE

September



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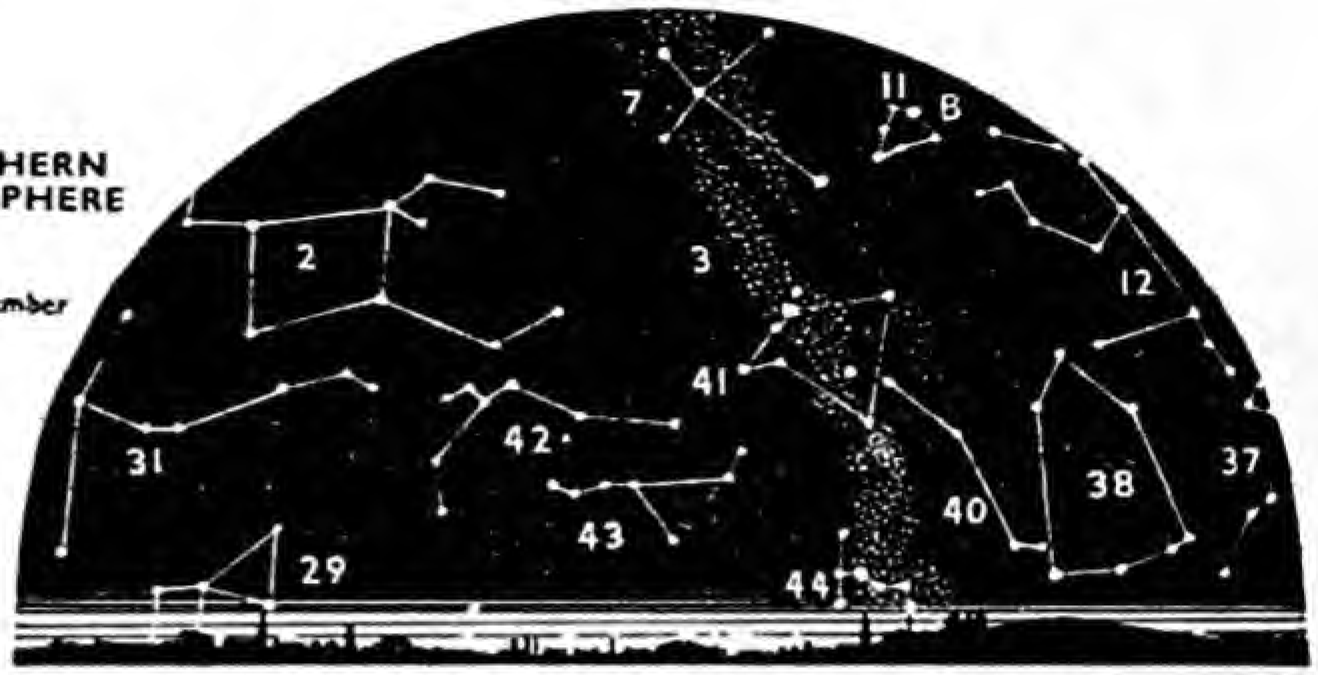

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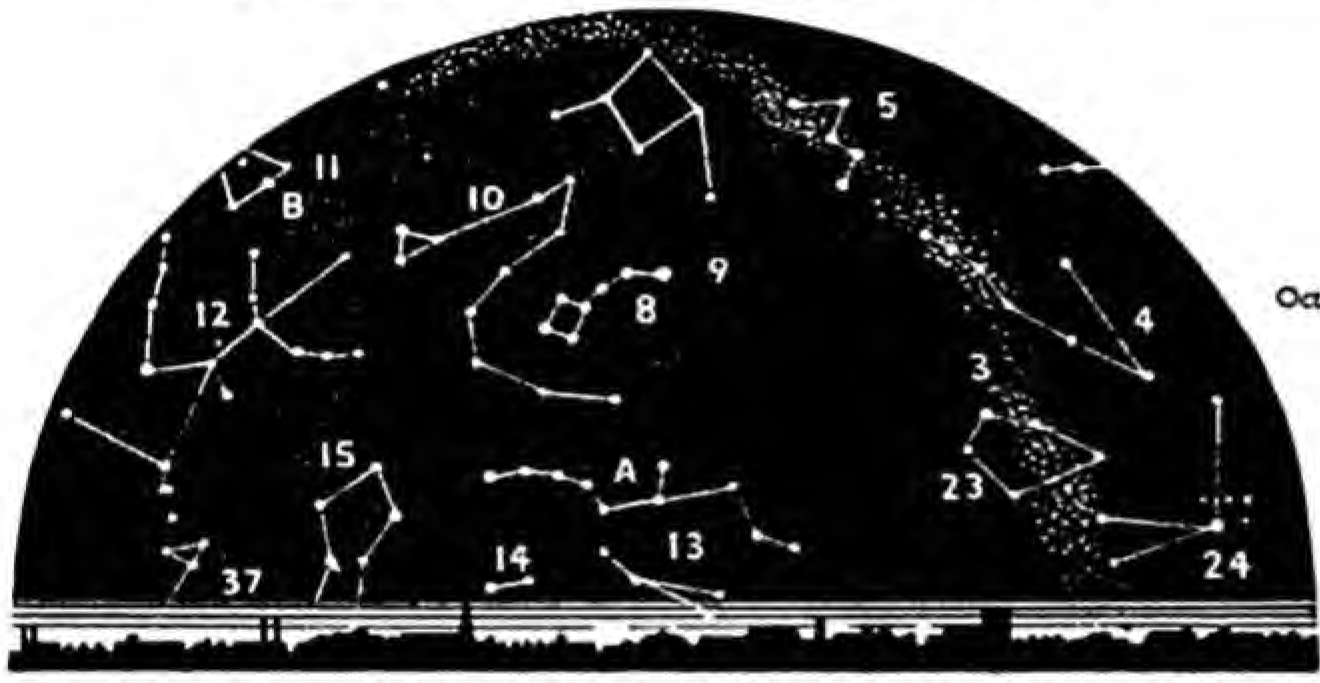
October



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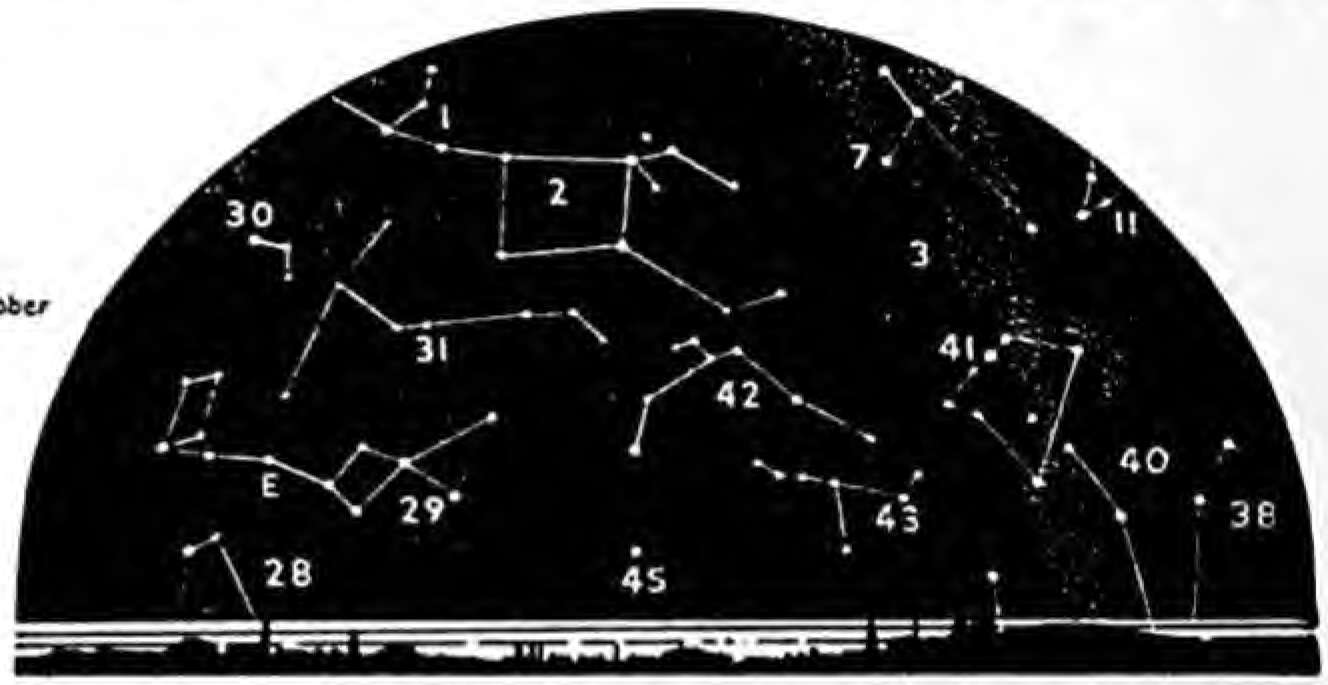

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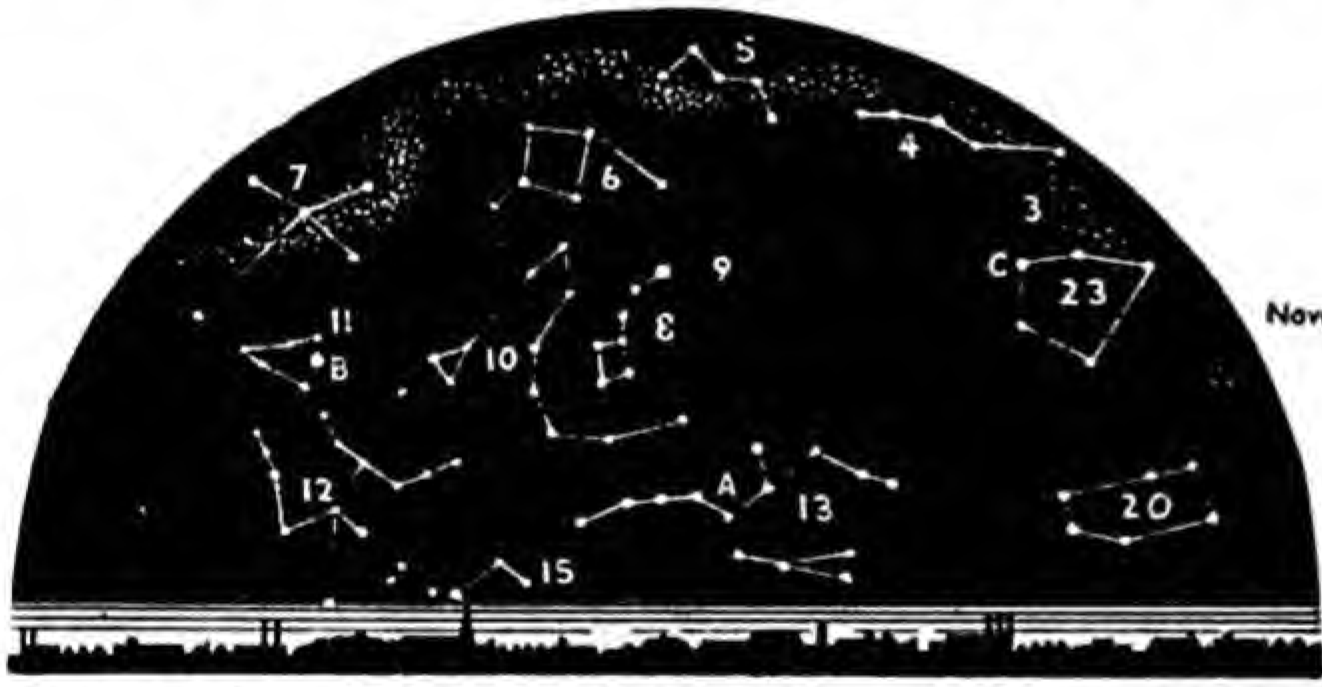
November



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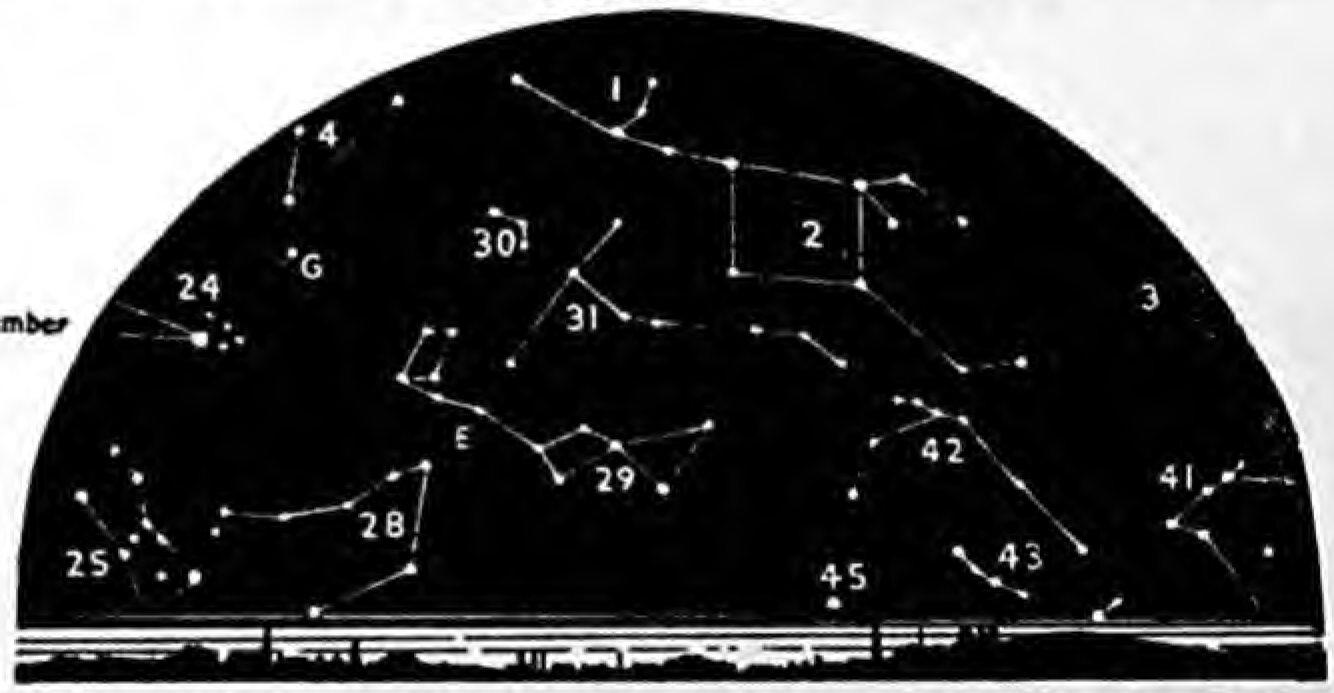

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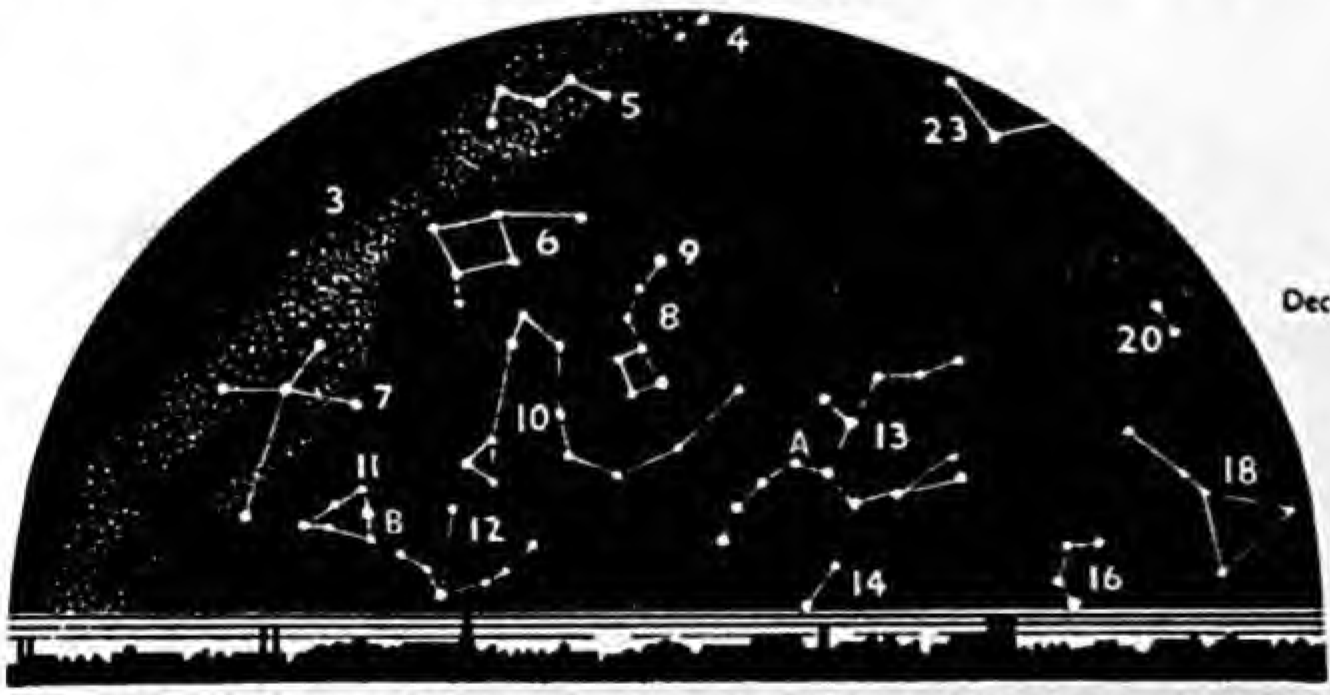
December



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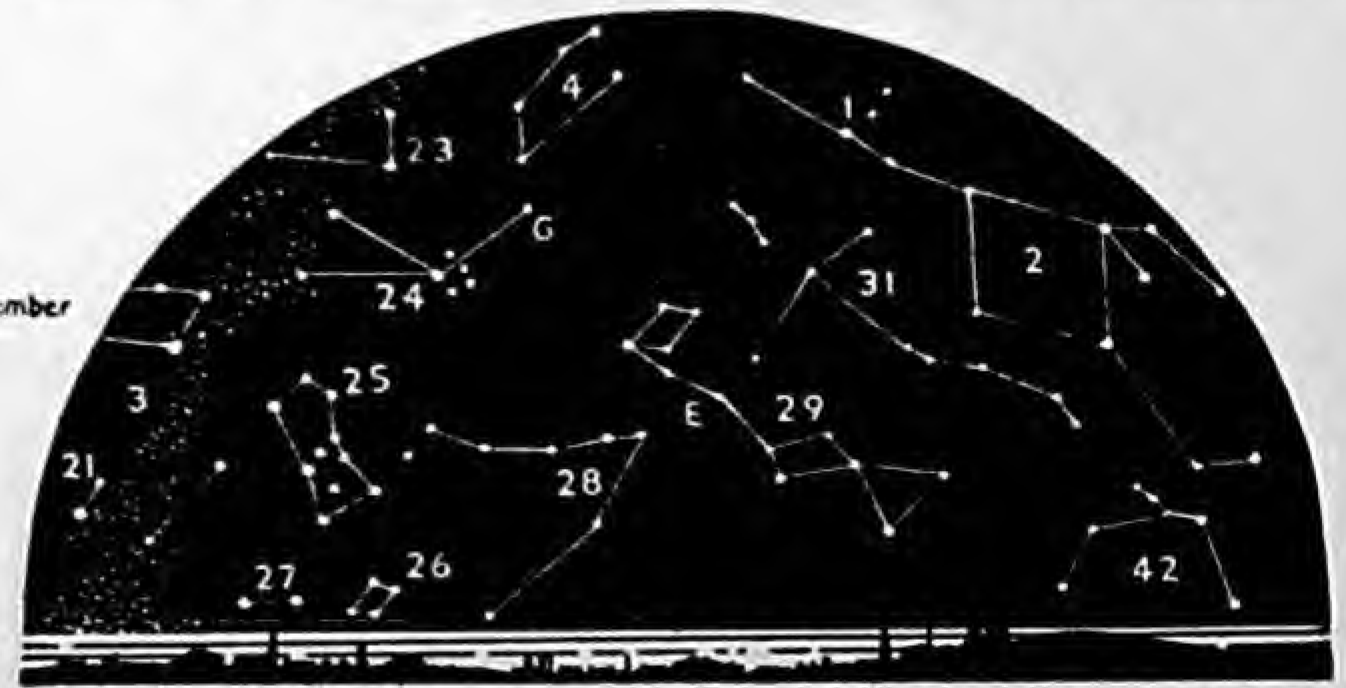
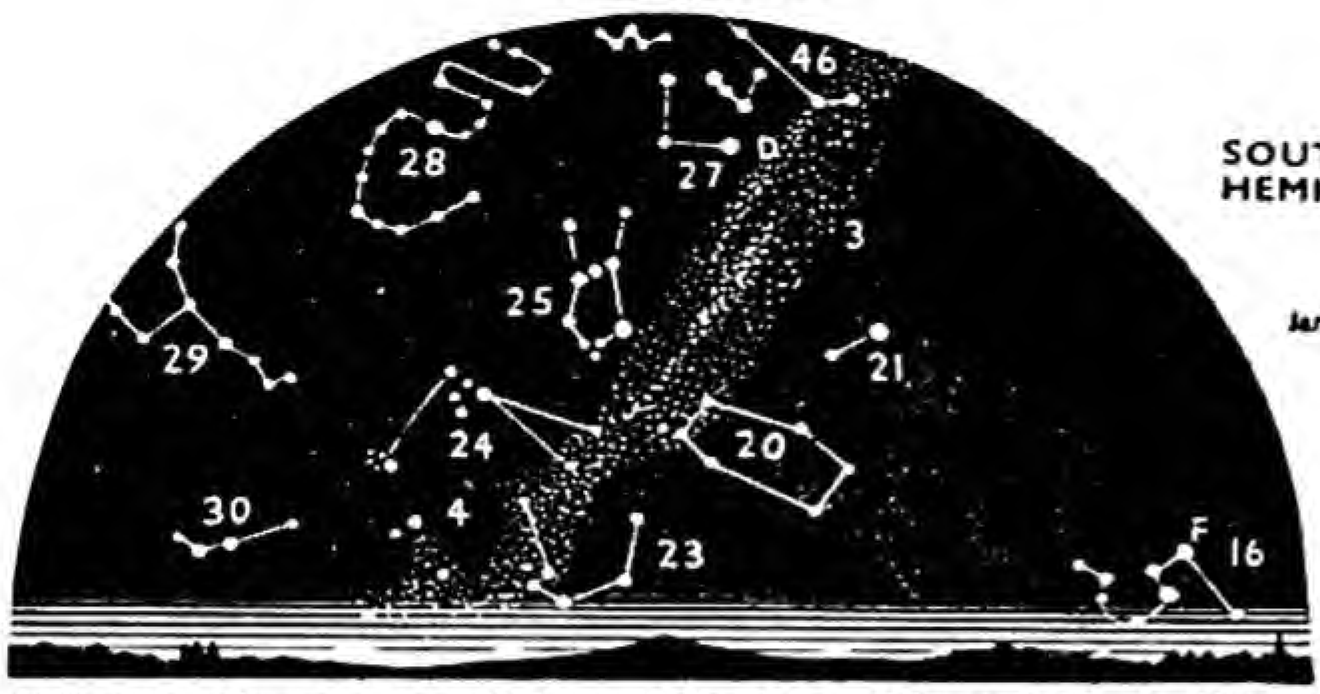


1 Andromeda 2 Pegasus 3 Milky Way 4 Perseus 21 Canis Minor 23 Auriga 24 Taurus 25 Orion 26 Lepus 27 Canis Major 28 Eridanus 29 Cetus 31 Pisces 42 Aquarius E Mira G Pleiades

SOUTHERN HEMISPHERE

Looking North | Looking South

January



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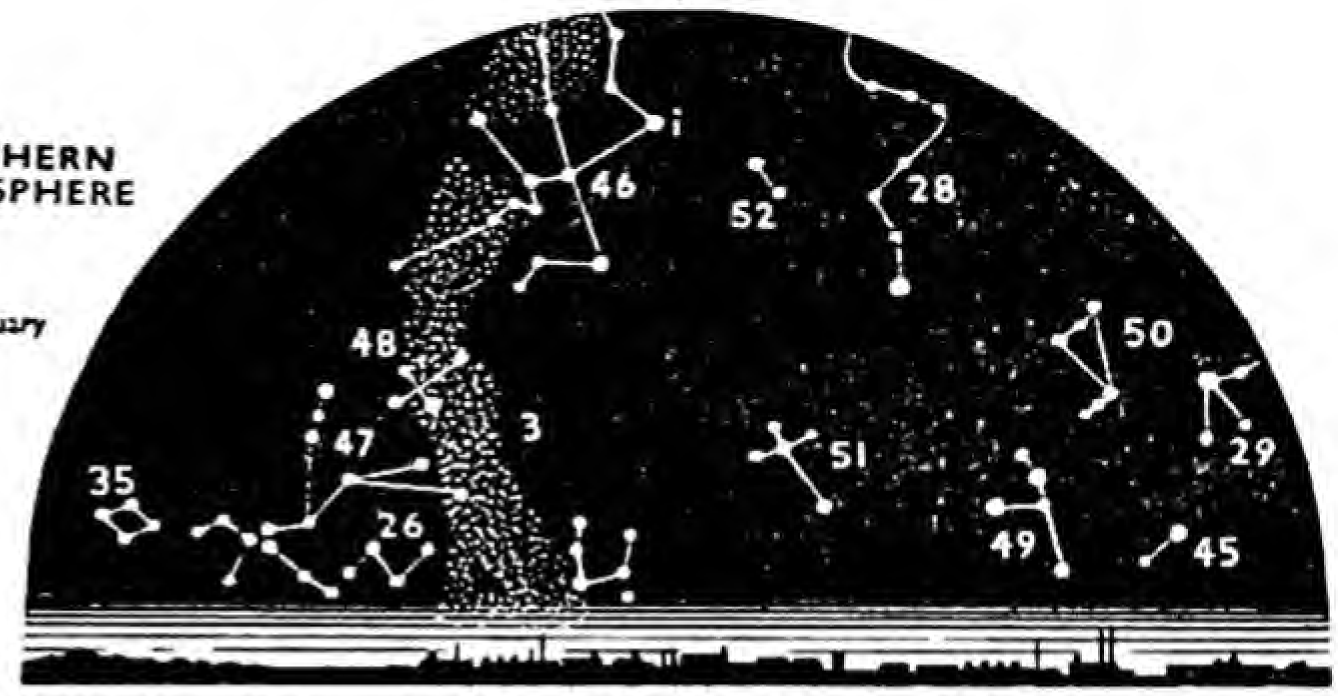

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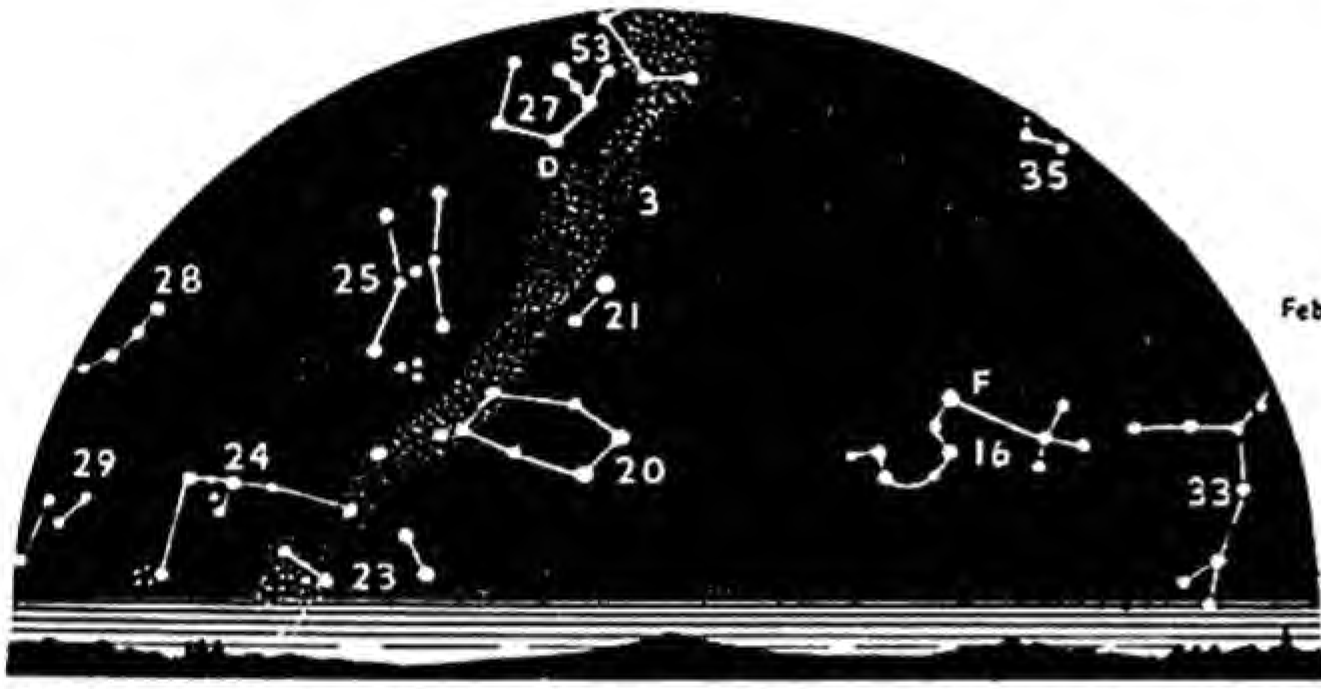
February



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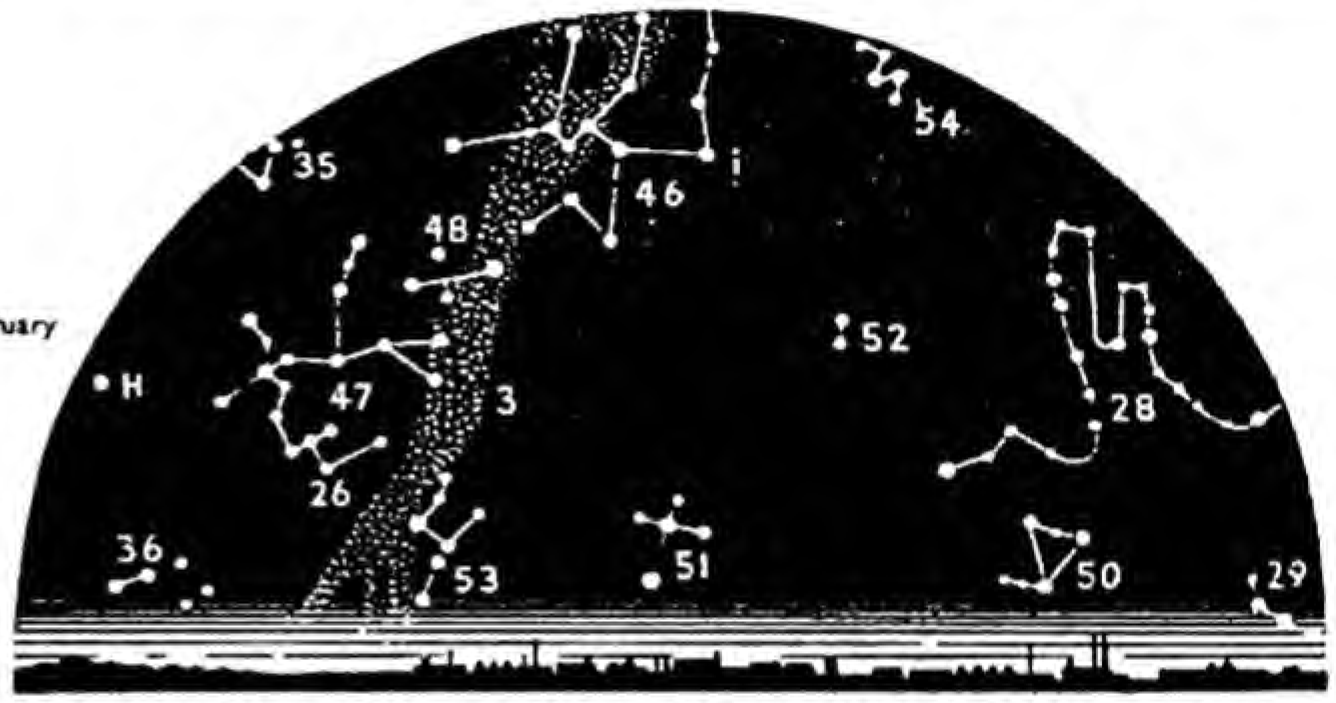

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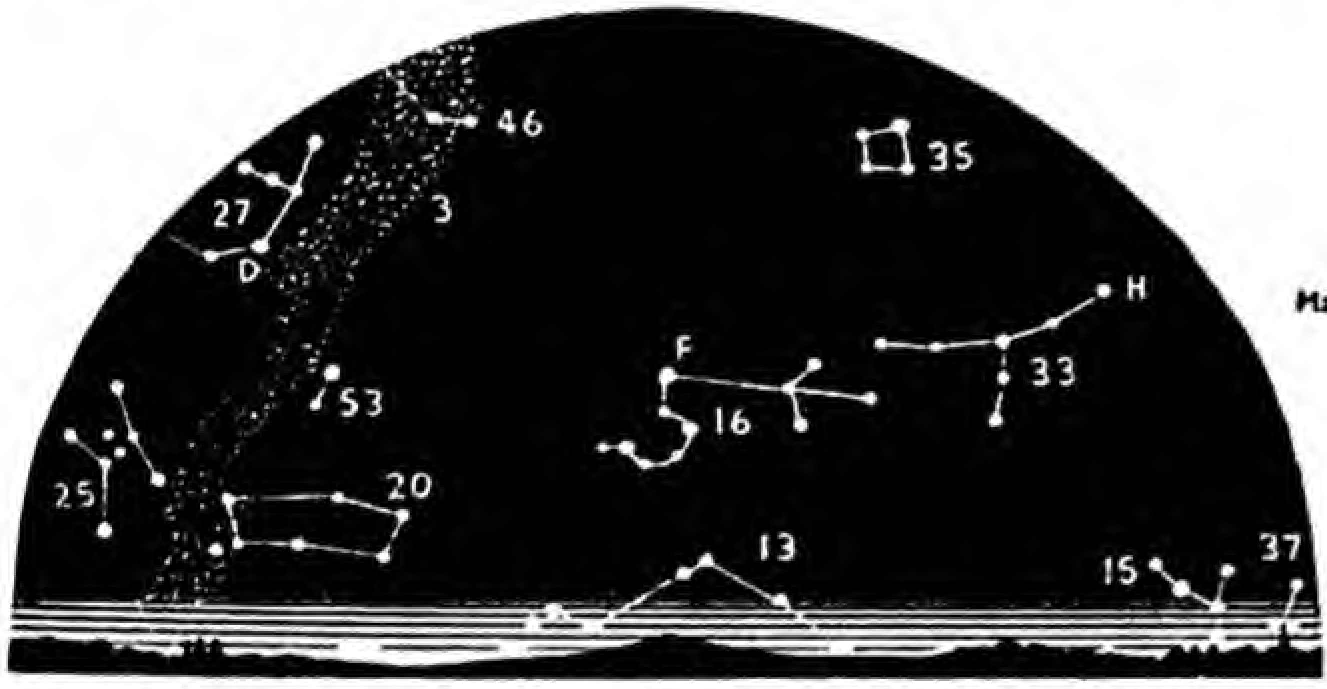
March



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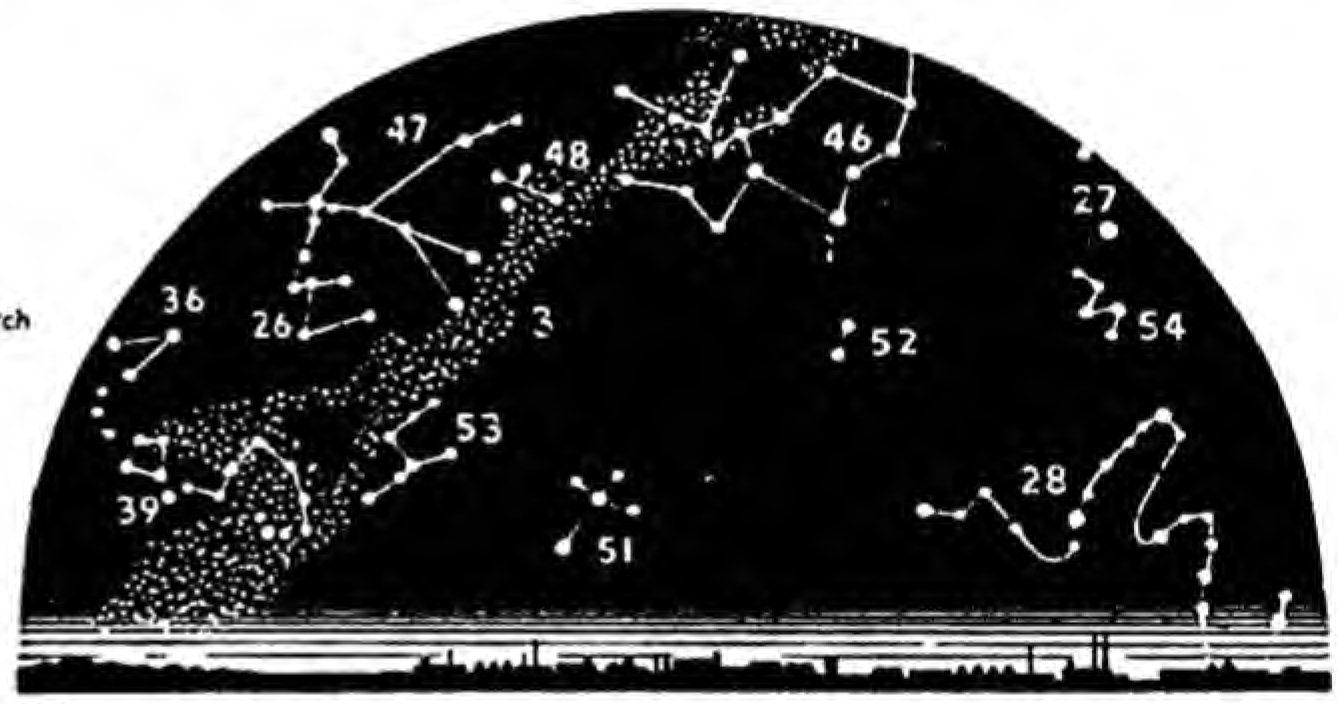

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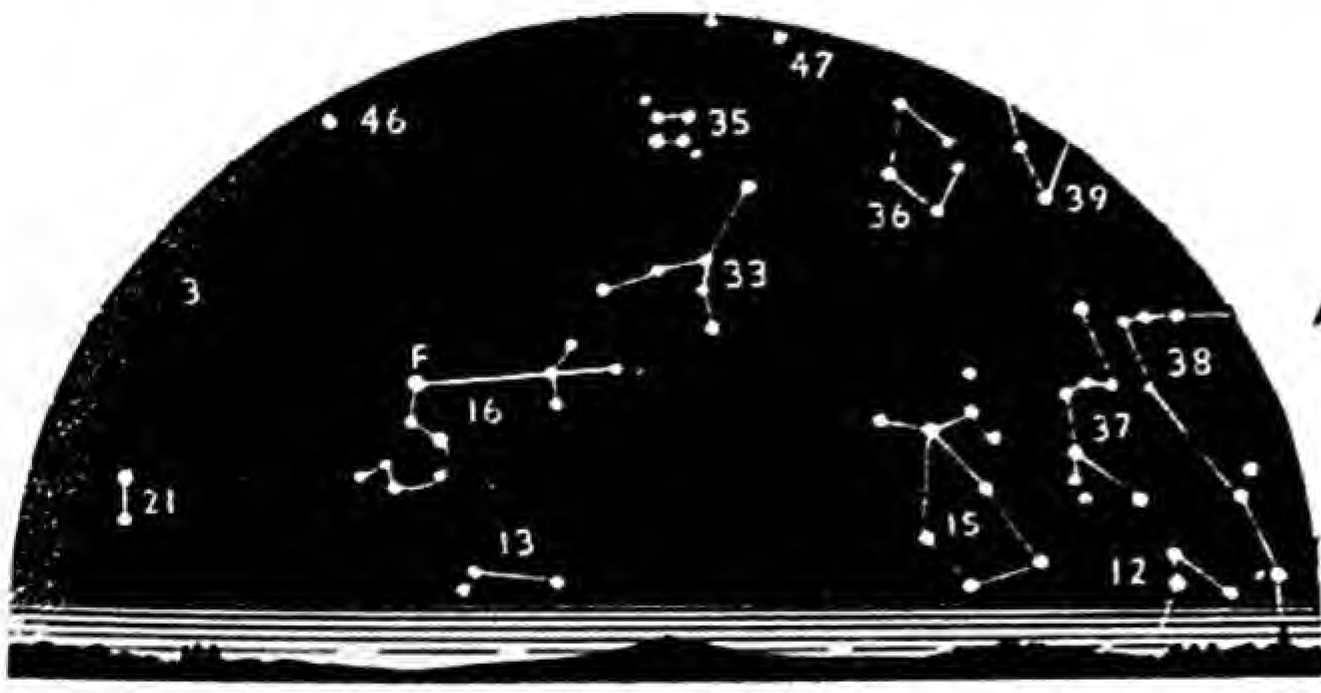
April



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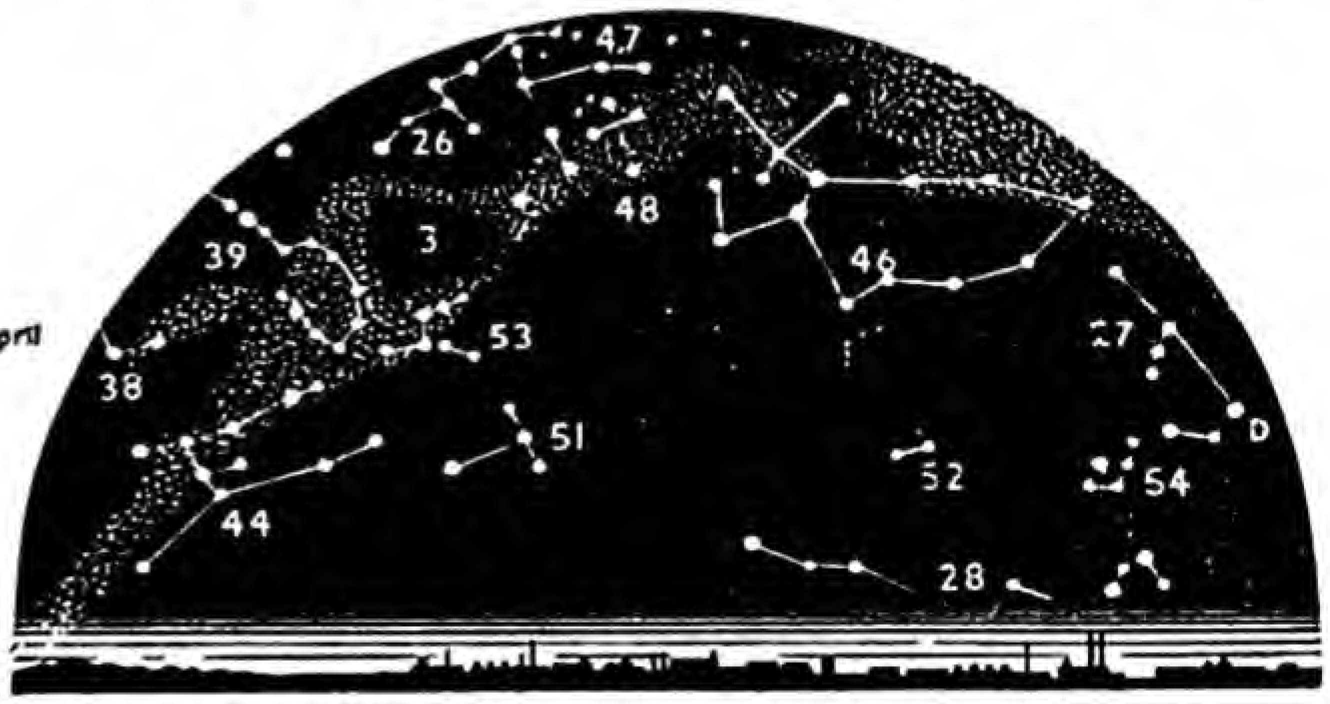

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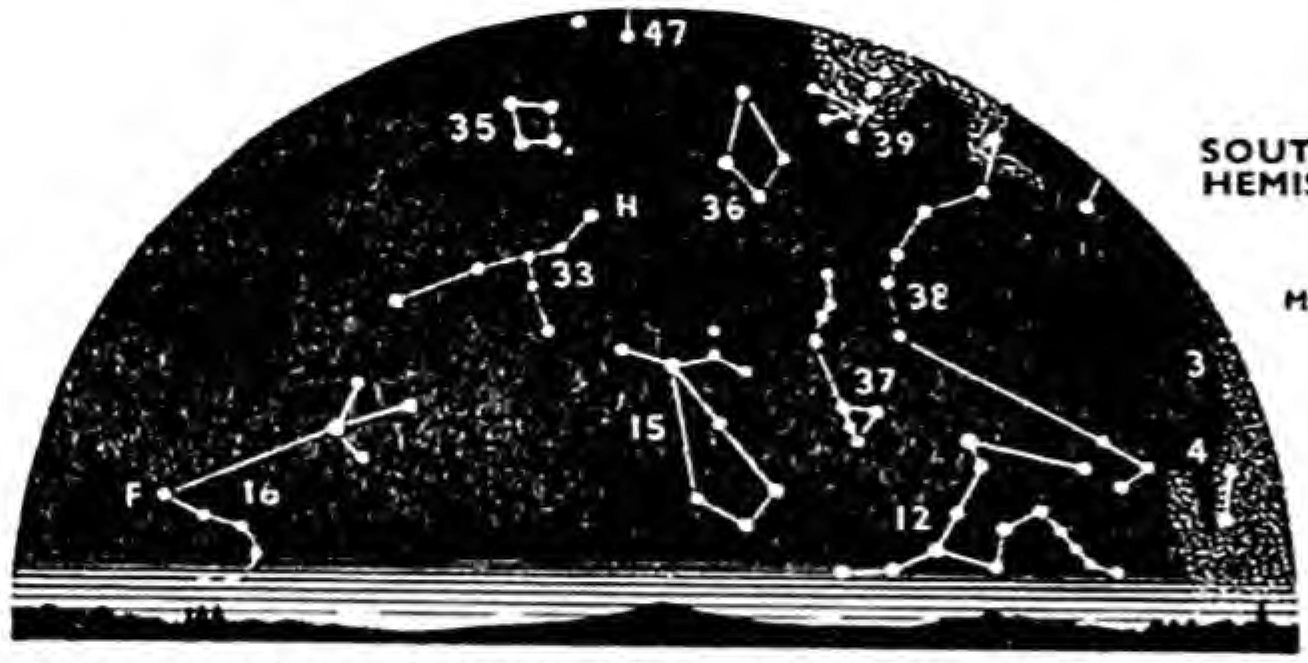
SOUTHERN HEMISPHERE

Looking North | Looking South

May



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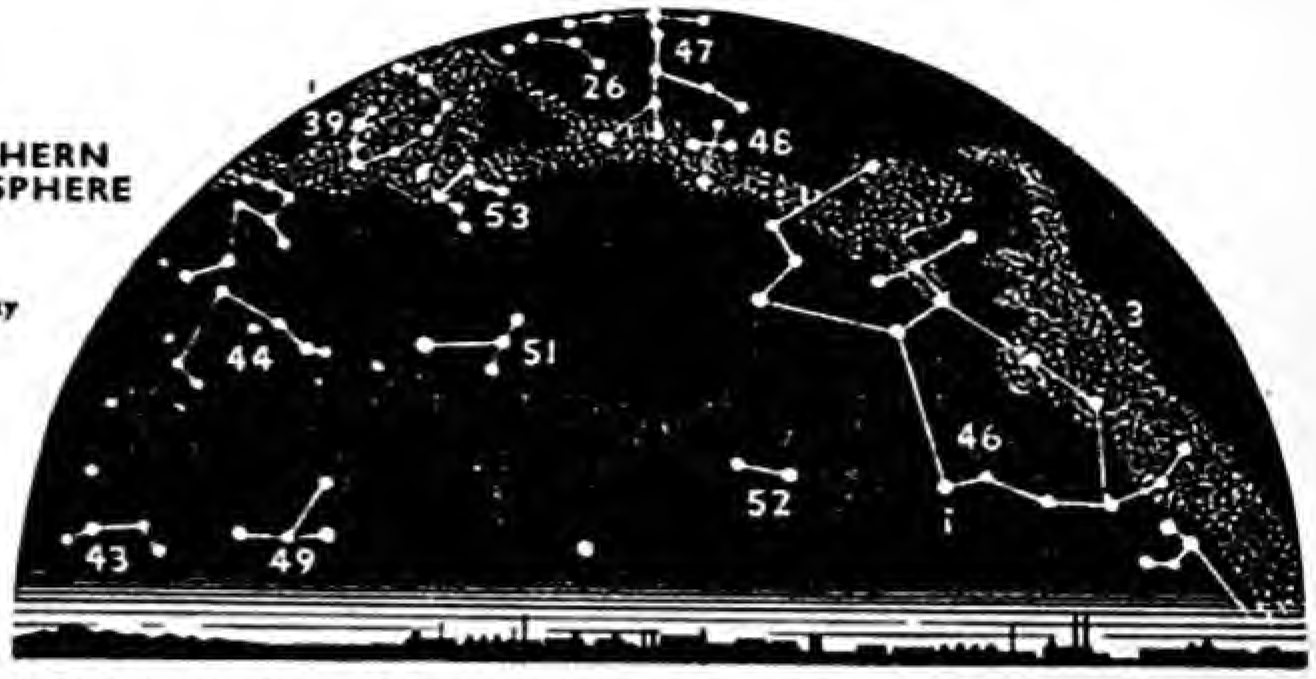

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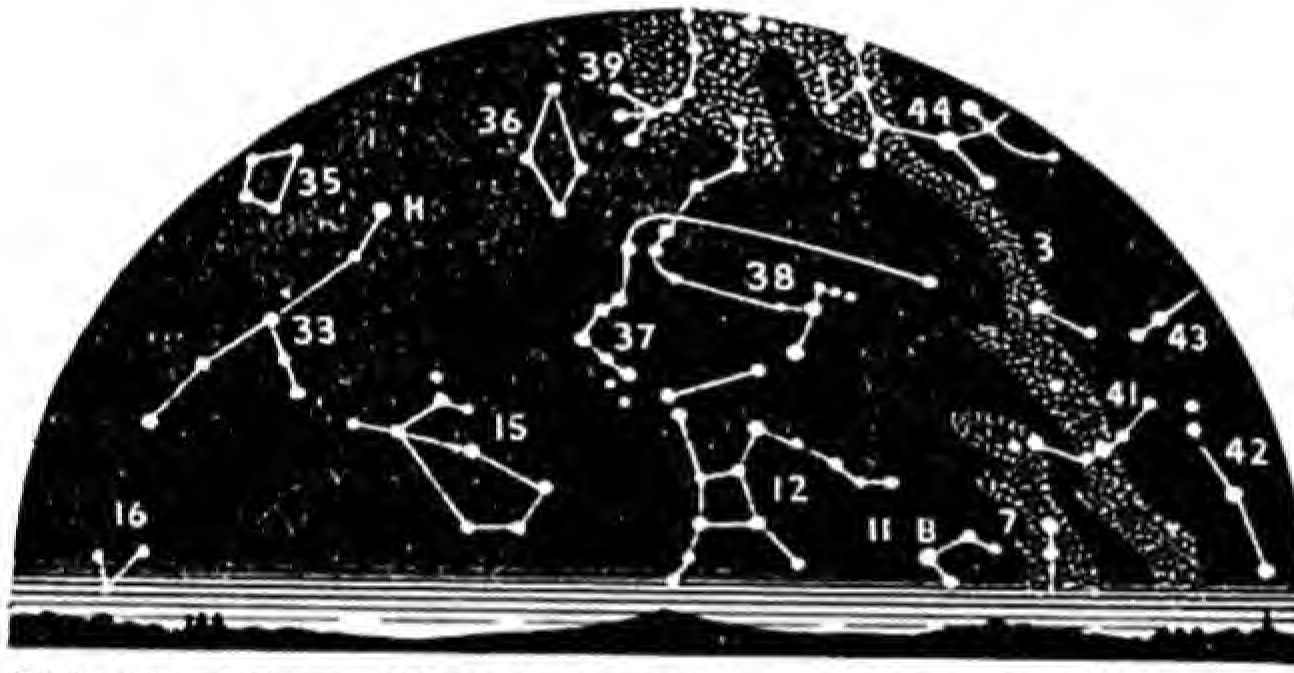
June



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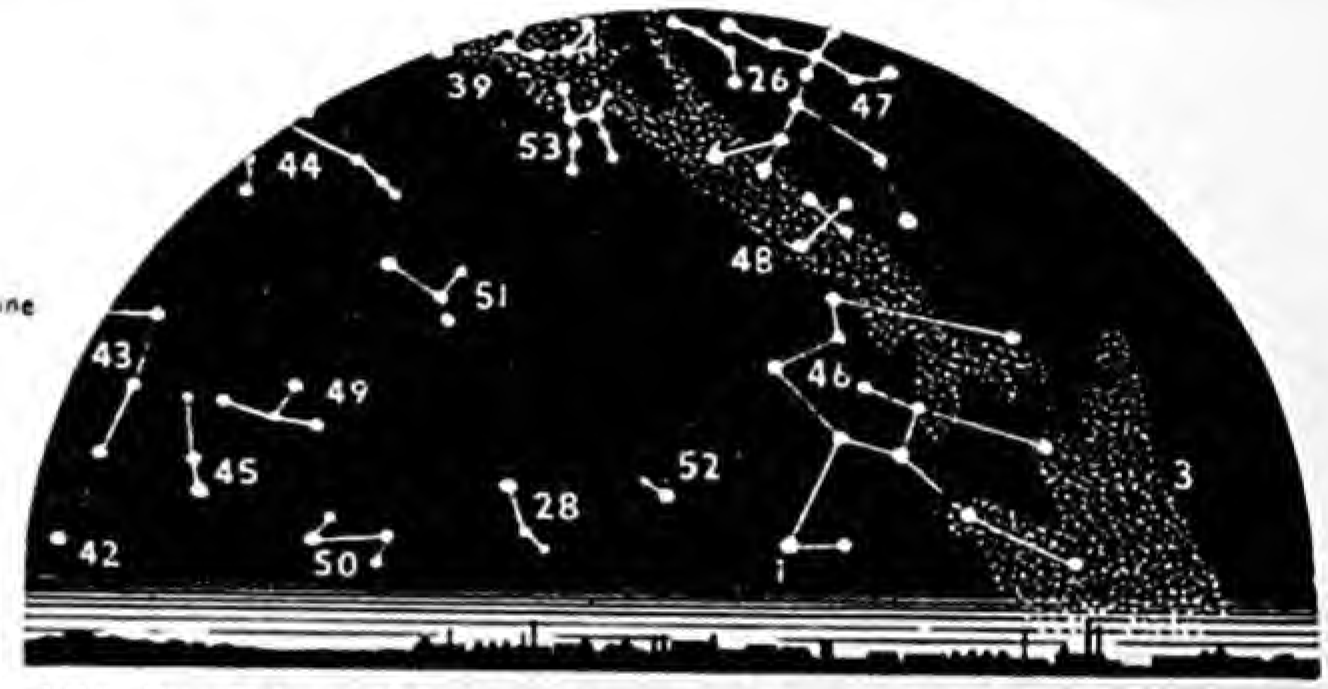

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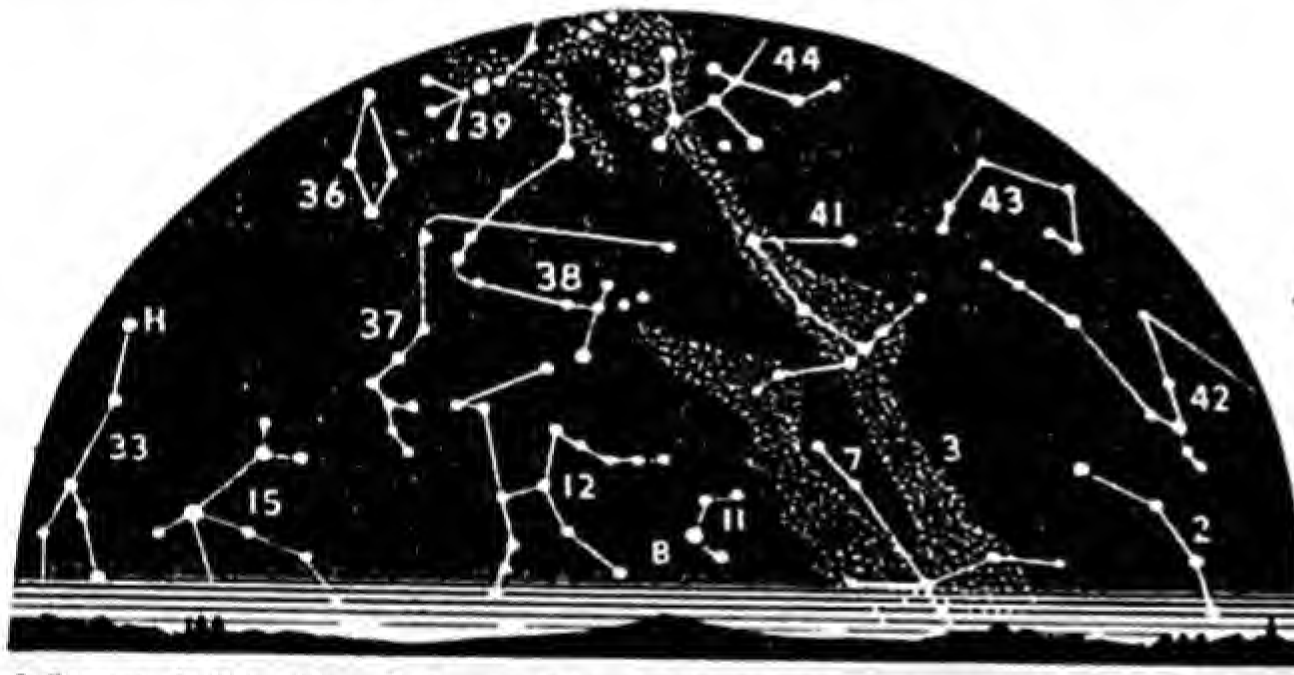
July



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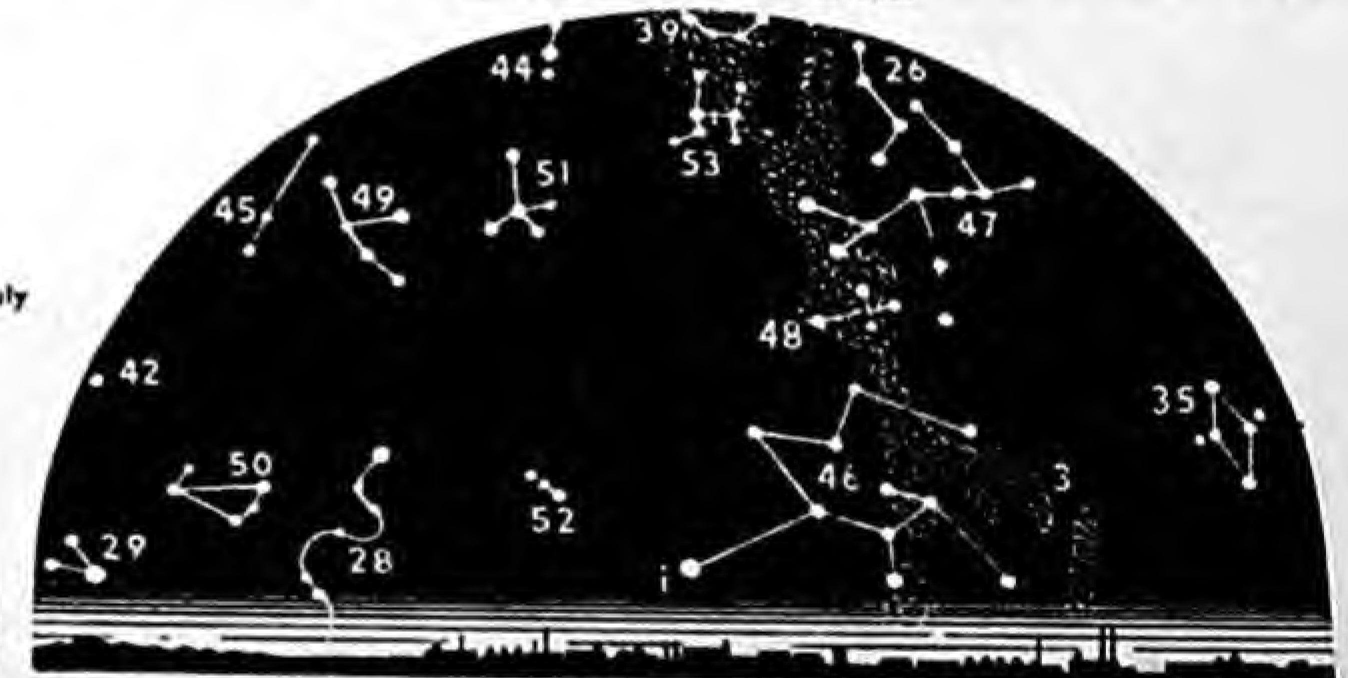

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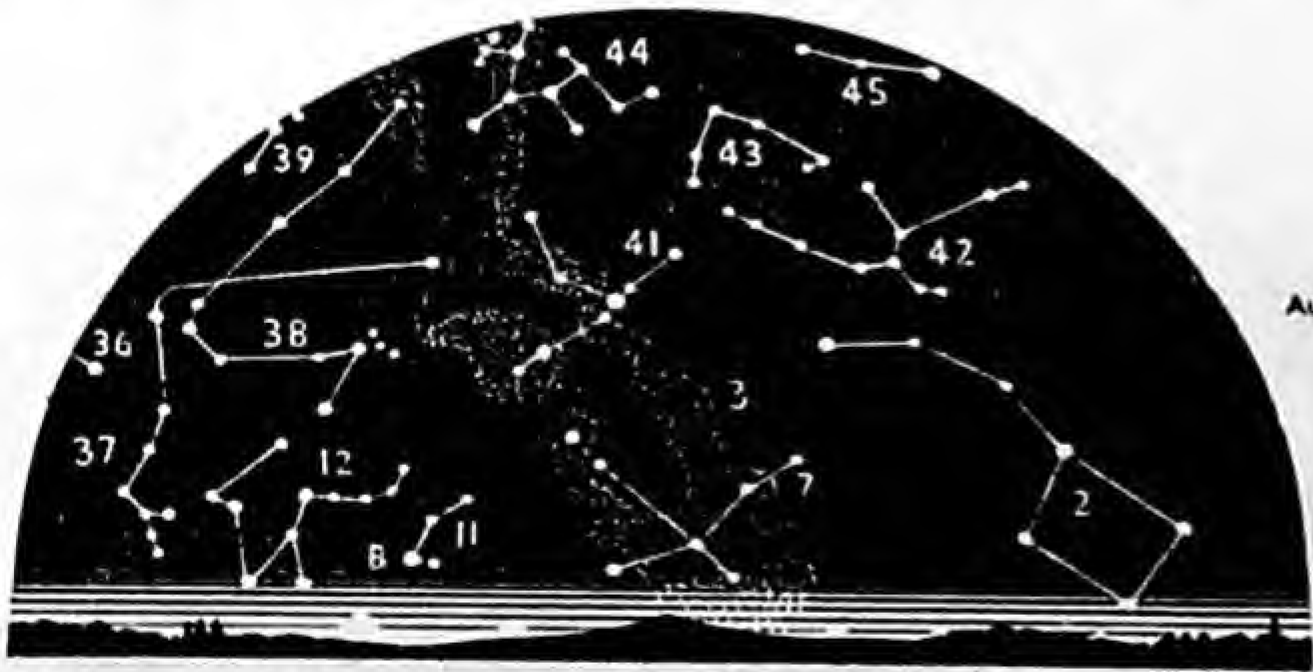
August



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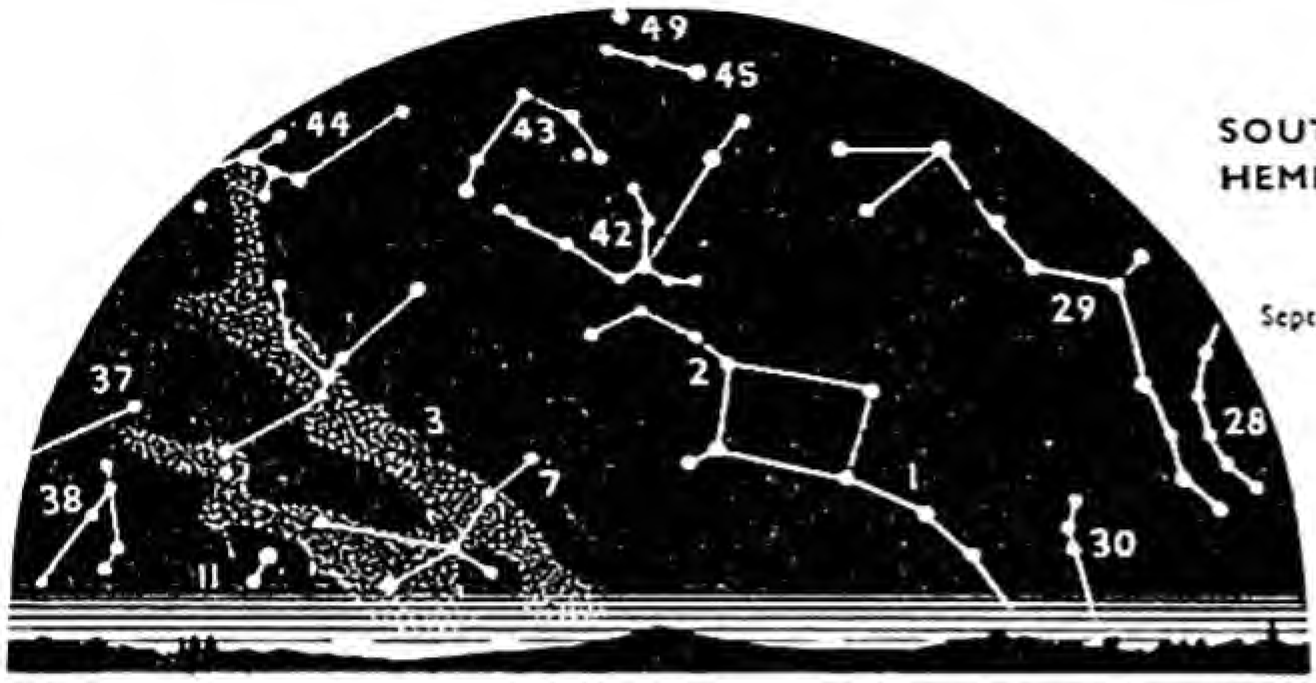
3 Milky Way 26 Lepus 28 Eridanus 29 Cetus 44 Sagittarius 45 Piscis Australis 46 Argo 47 Centaurus 48 Southern Cross 49 Grus 50 Phoenix 51 Pavo 52 Reticulum I Canopus

Looking North

Looking South

SOUTHERN HEMISPHERE

September



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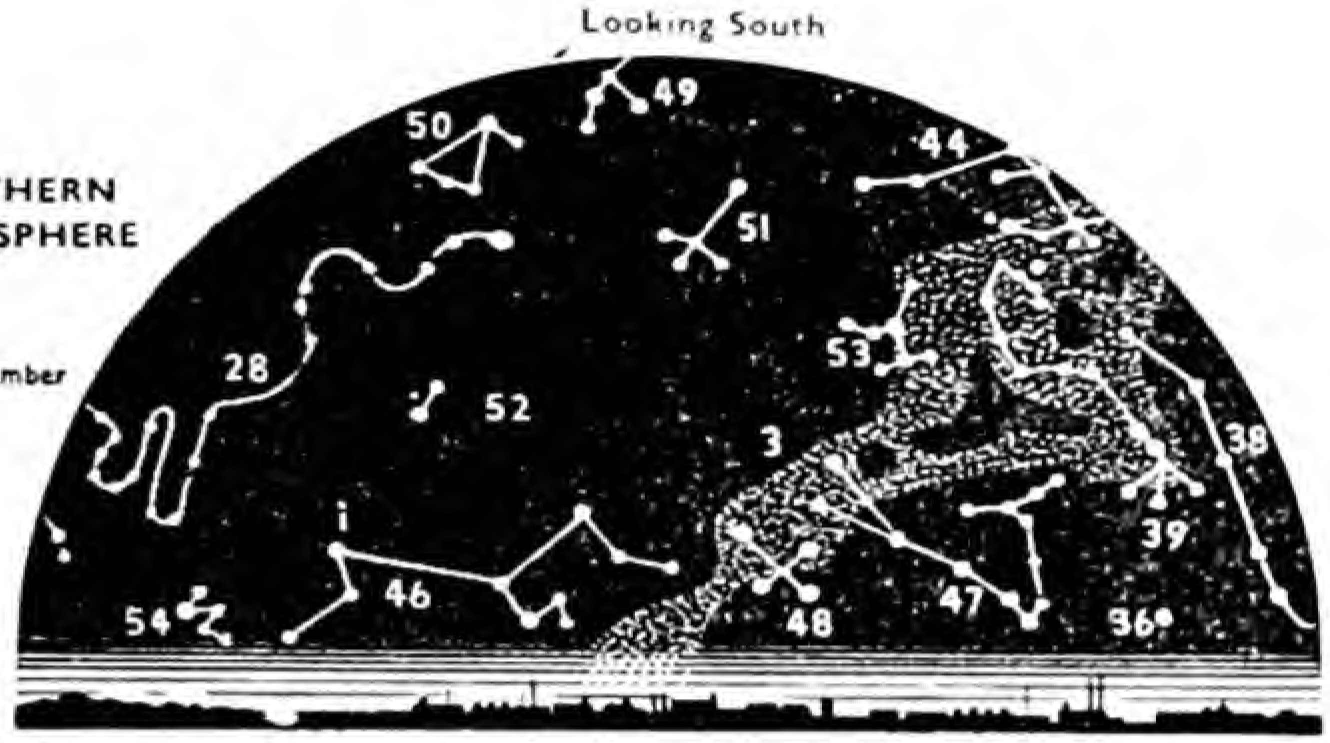

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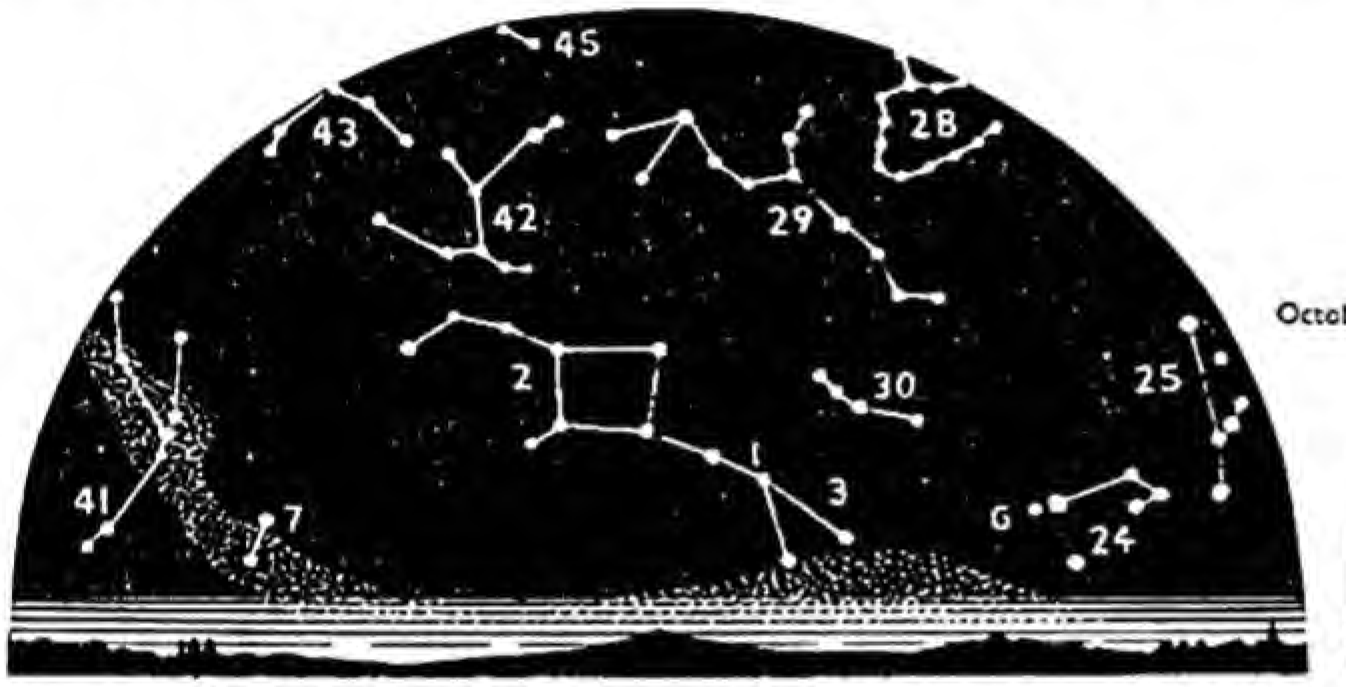
October



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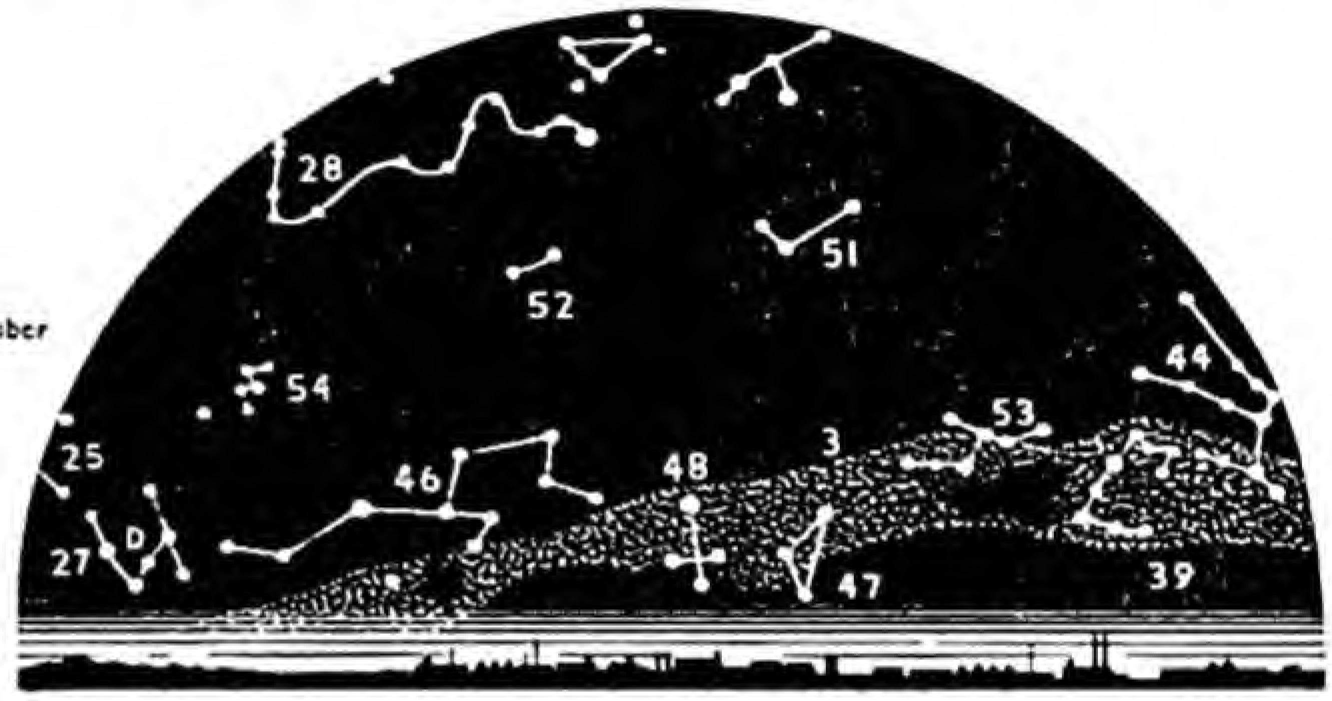

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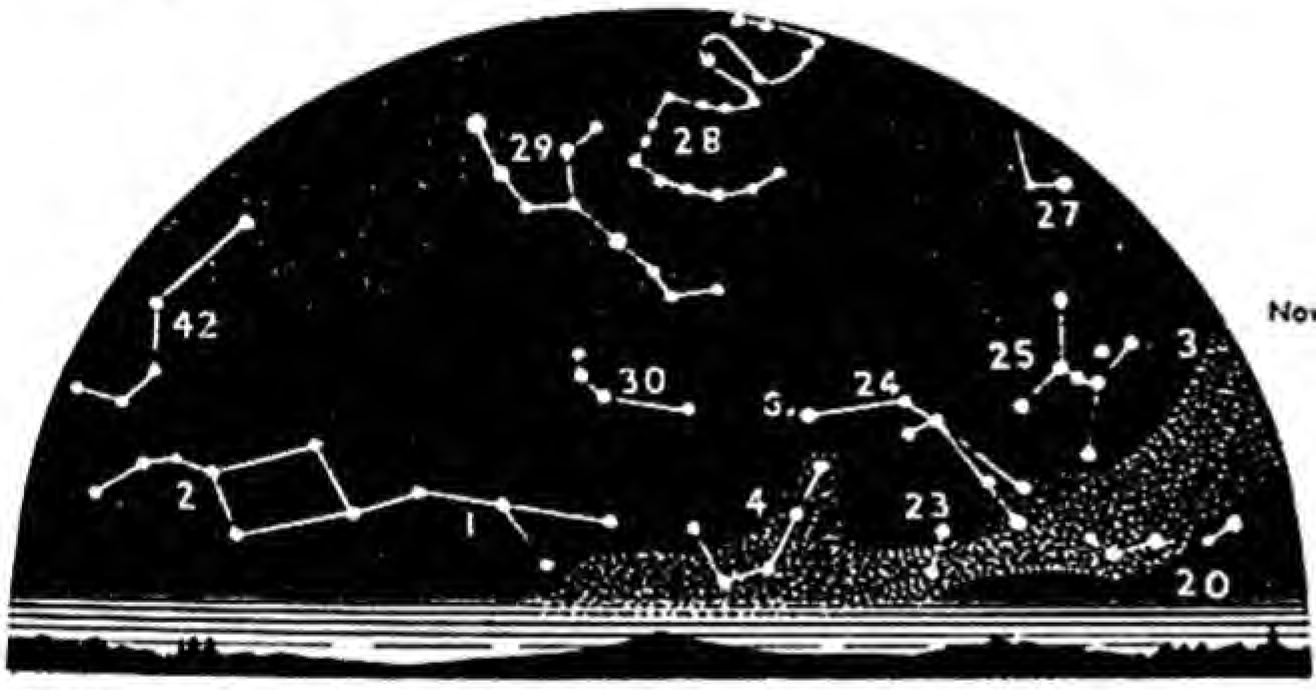
November



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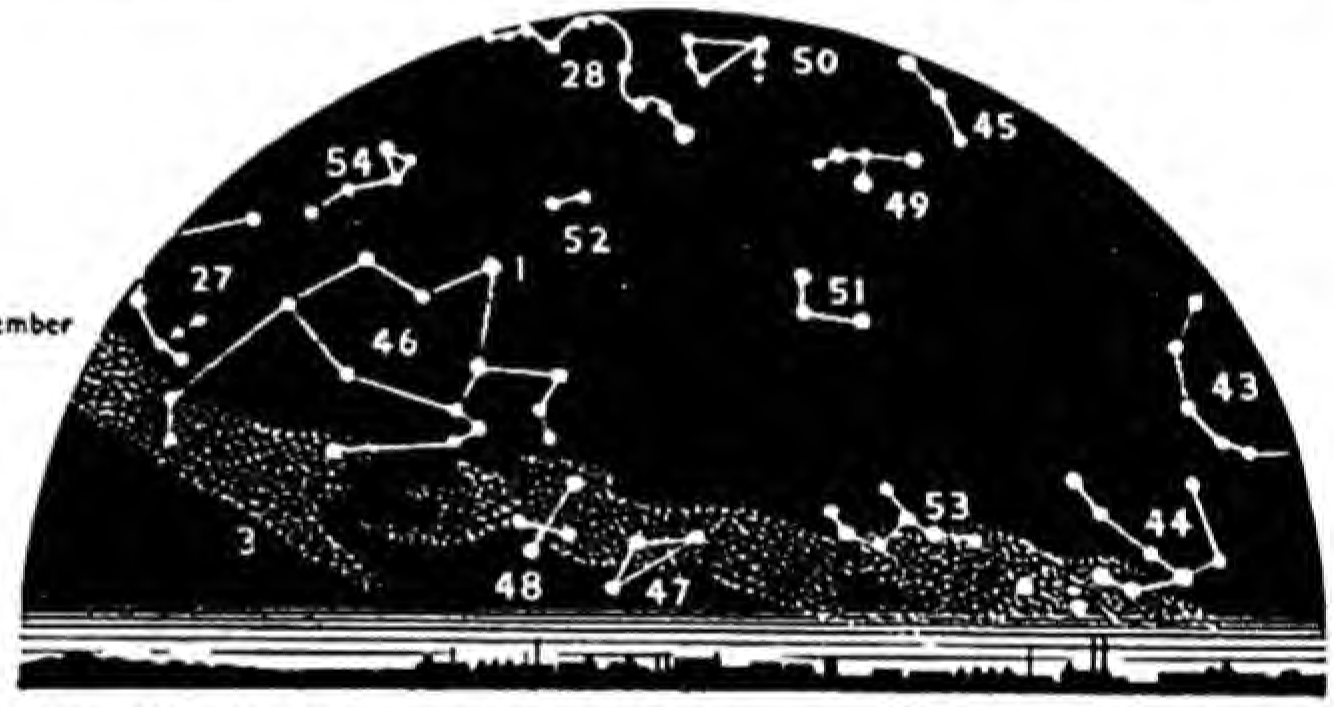

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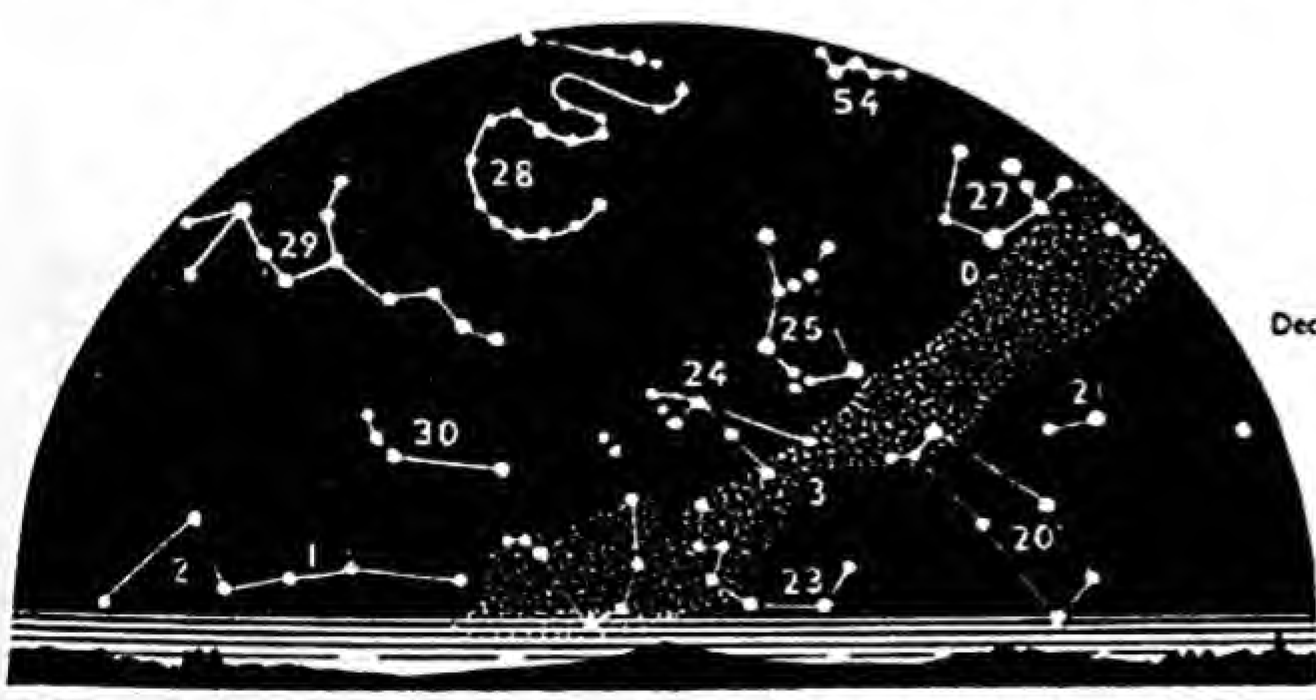
December



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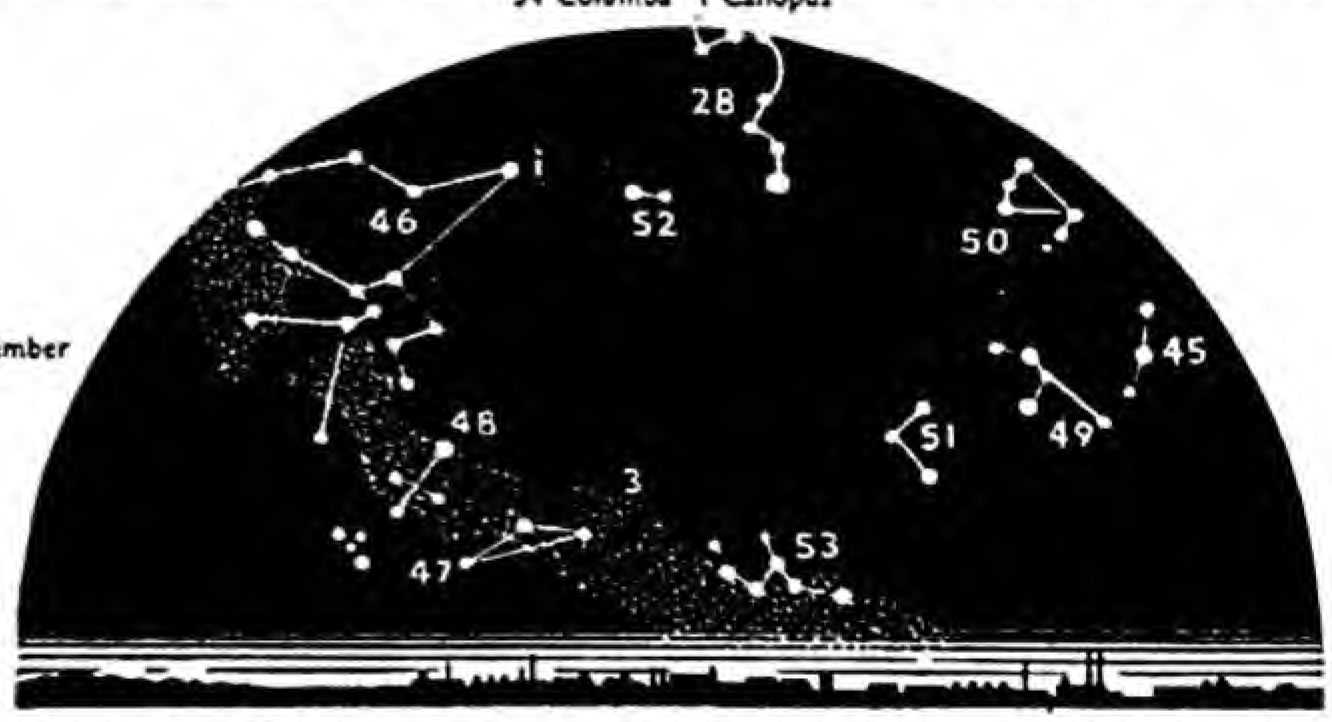


3 Milky Way 28 Eridanus 45 Piscis Australis 46 Argo 47 Centaurus 48 Southern Cross 49 Grus 50 Phoenix 51 Pavo 52 Reticulum 53 Ara 1 Canopus

See also THE ASTRONOMER AT WORK

PRESSURES

FORCE is that which is required to set a stationary body moving or to alter its movement when it has started. It is usually measured in pounds weight or in gm. weight.

PRESSURE is the force applied to unit area of a surface.

Example 1: A man weighs 180 lb. The area of his shoes in contact with the ground totals 40 sq. in. The pressure upon the ground is $\frac{180 \text{ lb.}}{40 \text{ sq. in.}} = 4{\cdot}5$ lb. per sq. inch.

Example 2: On a pair of ice skates, his weight is supported by two steel blades each having 2 sq. in. in contact with the ice. The pressure is now $\frac{180 \text{ lb.}}{4 \text{ sq. in.}} = 45$ lb. per sq. in.

Example 3: When he applies his full weight to a sharp spade, the area in contact with the ground is $\frac{1}{2}$ sq. in. The pressure is now $\frac{180 \text{ lb.}}{\frac{1}{2} \text{ sq. in.}} = \frac{180 \times 2}{1}$ lb. per sq. in. $= 360$ lb. per sq in.

Example 4: Wearing snow shoes, the total area of contact is 400 sq. in. The pressure is $\frac{180 \text{ lb.}}{400 \text{ sq. in.}} = {\cdot}45$ lb. per sq. in.

THE PRESSURE OF THE AIR. This varies continually, depending upon weather conditions and the height above sea level. It is measured, usually, with a mercury barometer.

Average values at sea level. (These are not *exactly* equivalent to each other.)

30 in. of mercury — 14·7 lb. per sq. in.
76 cm. of mercury — 1,013 millibars

Calculation of pressure in lb. per sq. in. when the mercury barometer reads 30 in.

Consider a column of mercury 1 sq. in. in area, supported by the air pressure on 1 sq. in.

Volume of mercury = 30 in. × 1 sq. in. = 30 cub. in. $= \frac{30}{12 \times 12 \times 12}$ cub. ft.

1 cub. ft. of water weighs 62·4 lb.

$\therefore \frac{30}{12 \times 12 \times 12}$ cub. ft. weigh $\frac{30 \times 62{\cdot}4}{12 \times 12 \times 12}$ lb.

But mercury is 13·56 times as heavy as water.

$$\therefore \text{weight of mercury} = \frac{30 \times 62{\cdot}4 \times 13{\cdot}56}{12 \times 12 \times 12} = 14{\cdot}7 \text{ lb.}$$

$\therefore$ *Pressure is* 14·7 *lb. per sq. in.*

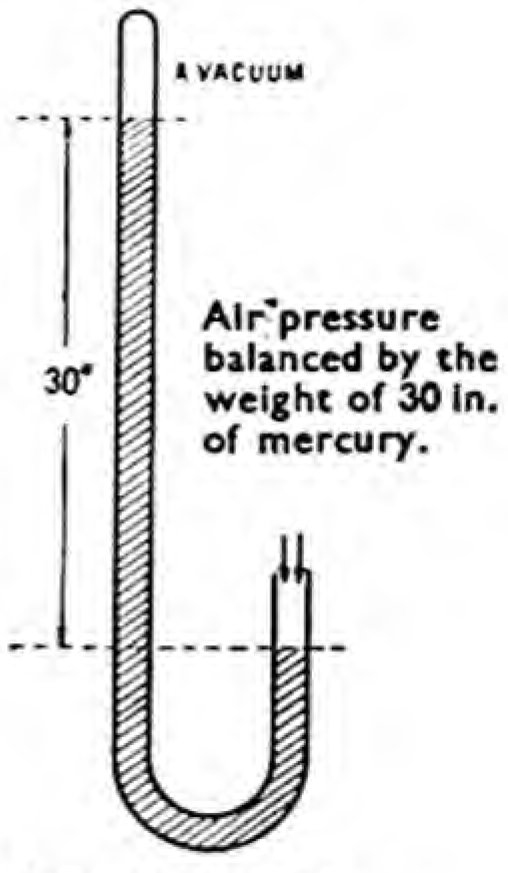
Calculation of pressure in grammes per sq. cm. when the mercury barometer reads 76 cm.

Volume of mercury column 76 cm. high and 1 sq. cm. in area = 76 cm. × 1 sq. cm. = 76 c.c.

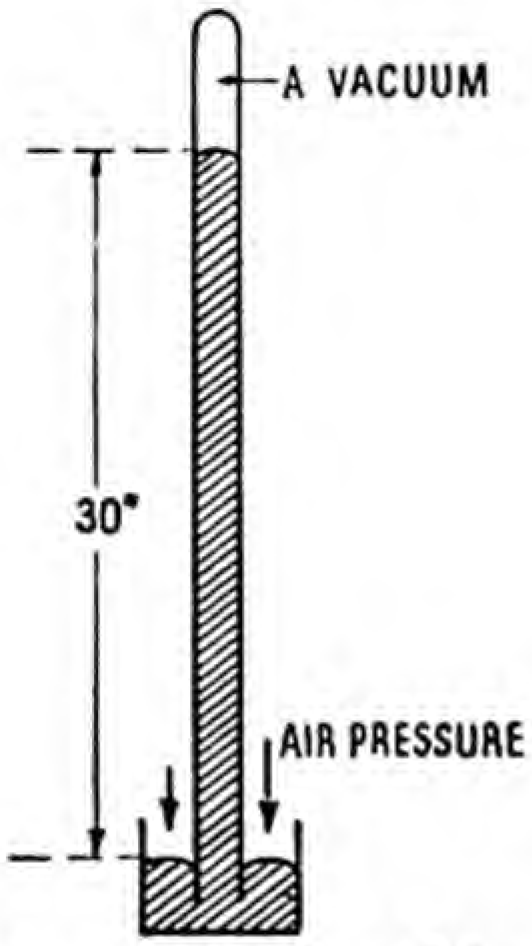
1 c.c. of mercury weighs 13·56 gm.

$\therefore$ 76 c.c. of mercury weigh 76 × 13·56 = 1,031 gm.

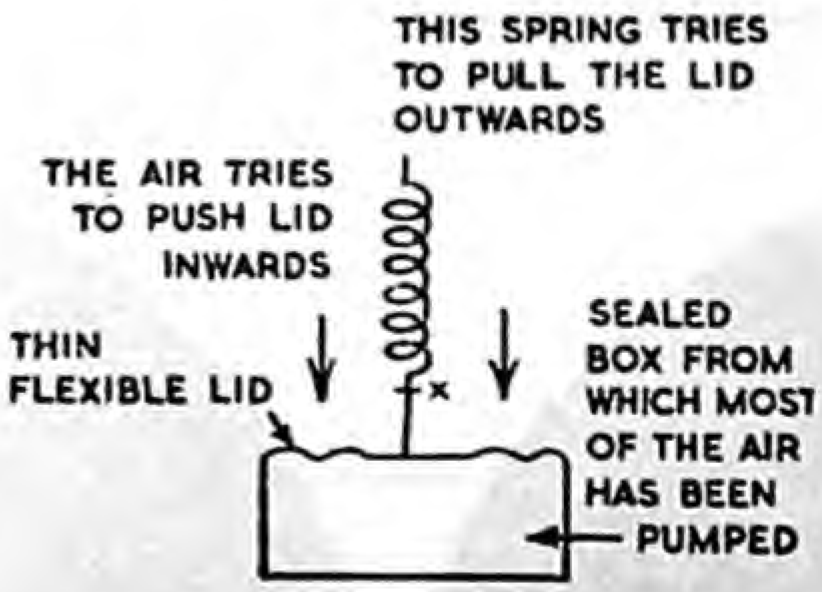
$\therefore$ Pressure = 1,031 gm. per sq. cm.



One form of mercury barometer.

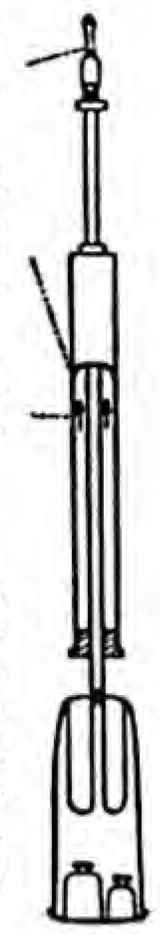


A more common form of simple mercury barometer.



The principle of the aneroid barometer

There is a continual tug-of-war between the air pressure and the spring, the lid of the box moving in and out as the air pressure changes. A sensitive system of levers connected to X moves the pointer round a dial.



The pressure of the air, in pounds per square inch, can be found by loading the handle of a cycle pump with weights until it is just able to overcome the air pressure and begins to pull out the piston.

Result of an experiment with a cycle pump to find the atmospheric pressure.

Weight supported = 6 lb.
Diameter of pump barrel = $\frac{3}{4}$ in.

Calculation: Area of a circle $= \pi r^2$.

$$d = \tfrac{3}{4} \text{ in.}$$
$$r = \frac{d}{2} = \tfrac{3}{8} \text{ in.}$$

$\therefore$ Area of circle $= \frac{22}{7} \times \frac{3}{8} \times \frac{3}{8} = {\cdot}44$ sq. in.

Air pressure on ·44 sq. in. = 6 lb.

$\therefore$ Air pressure on 1 sq. in. $= \frac{6}{{\cdot}44} = 13{\cdot}6$ lb.

THE ALTIMETER is an aneroid barometer which is carried in an aeroplane to give the height above the ground (altitude). The dial is marked in thousands of feet above the ground instead of the usual inches of mercury. As weather can cause the altimeter to change, it has to be set to zero before each flight.

APPROXIMATE PRESSURES AT VARIOUS ALTITUDES

	Air pressure per sq. in.	
Sea level	14½ lb.	
1 mile	11½ lb.	Ben Nevis
2 miles	9½ lb.	
3 miles	7¾ lb.	Alps
4 miles	6½ lb.	
5 miles	5 lb.	Mt. Everest
6 miles	4 lb.	
7 miles	3½ lb.	
8 miles	2½ lb.	
9 miles	2 lb.	
10 miles	1½ lb.	
14 miles	½ lb.	Highest ascent by man (balloon record)

THE WATER BAROMETER. The normal atmospheric pressure can support a column of mercury 30 inches high. But mercury is 13·56 times as dense as water, so it will take a column of water 13·56 times this height to make up the same pressure.

30 in. × 13·56 = 406·8 in.

$$= \frac{406{\cdot}8}{12} \text{ ft.} = 33{\cdot}9 \text{ ft.}$$

The air pressure should, in theory, support approximately 34 feet of water in a vertical column. In practice it is a little less, because water evaporates more easily than mercury, and so the vacuum above the column is less perfect.

THE GAS LAWS

All common gases may be assumed to obey these laws.

BOYLE'S LAW. The pressure of a given quantity of gas is inversely proportional to the volume (the temperature being unchanged).

Example 1: Double the pressure, half the volume.

Example 2: 10 times the pressure, $\frac{1}{10}$ of the volume.

Example 3: $\frac{1}{5}$ of the pressure, 5 times the volume.

Formula: $P_1 V_1 = P_2 V_2$.

Example 1:

First pressure $= P_1 = 1$ atmosphere.
First volume $= V_1 = 10$ cub. ft.
Second pressure $= P_2 = 5$ atmospheres.
Second volume, V_2, is required.

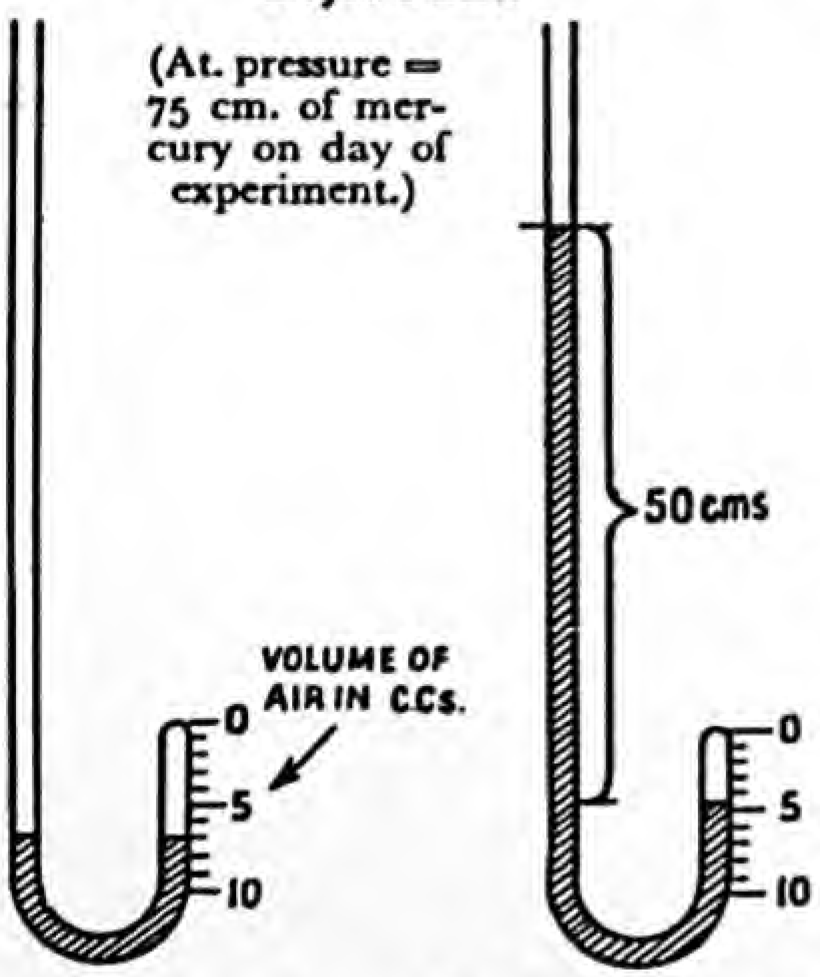
$$1 \times 10 = 5 \times V_2$$
$$\therefore \underline{2 = V_2}$$
$$\therefore \text{Volume} = \underline{2 \text{ cub. ft.}}$$

Example 2:

First pressure $= 19$ cm. of mercury.
First volume $= 100$ litres.
Second volume $= 25$ litres.
Second pressure is required.

$$P_1 V_1 = P_2 V_2$$
$$19 \times 100 = P_2 \times 25$$
$$\therefore 25 P_2 = 1{,}900$$
$$\underline{P_2 = 76 \text{ cm. of mercury.}}$$

A simple experiment to demonstrate Boyle's Law



1. Levels equal. Pressure = atmospheric = 75 cm. of mercury. Volume = 7 c.c.
$P_1 \times V_1 = 525$

2. More mercury added. "Head" of mercury = 50 cm. Pressure = 75 + 50 = 125 cm. of mercury. Volume = 4·2 c.c.
$P_2 \times V_2 = 125 \times 4{\cdot}2 = 525$

$$\therefore P_1 V_1 = P_2 V_2$$

CHARLES' LAW. A given quantity of gas expands by $\frac{1}{273}$ of its volume at 0°C. for each Centigrade degree rise in temperature (the pressure being unchanged). A more convenient definition : the volume of a given mass of gas is directly proportional to its absolute temperature, the pressure being unchanged.

Example: A gas occupies 100 c.c. at 0°C. (273°K.). It occupies 200 c.c. at 273°C. (546°K.), because 546 is double 273.

Formula:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Example: A gas occupies 60 cub. ft. at 27°C. What will be its volume at 77°C.?

$$\frac{60}{273 + 27} = \frac{V_2}{273 + 77}$$
$$\therefore \frac{60}{300} = \frac{V_2}{350}$$
$$\therefore \frac{1}{5} = \frac{V_2}{350}$$
$$\therefore \frac{350}{5} = \frac{V_2}{1}$$
$$\therefore V_2 = 70 \text{ cub. ft.}$$

THE GAS EQUATION (Boyle's and Charles' Laws combined).

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Example: A gas occupies 100 c.c. when the pressure is 80 cm. of mercury and the temperature is 47°C. What will be its volume at 120 cm. pressure and 87°C.?

$P_1 = 80$. $V_1 = 100$. $T_1 = 47°C. = 273 + 47 = 320°K.$

$P_2 = 120$. $V_2 = ?$. $T_2 = 87°C. = 273 + 87 = 360°K.$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$
$$\therefore \frac{80 \times 100}{320} = \frac{120 \times V_2}{360}$$
$$\therefore 25 = \frac{V_2}{3}$$
$$\therefore 75 = V_2.$$

Normal Temperature and Pressure (N.T.P.) or Standard Temperature and Pressure (S.T.P.) = 0°C. and 76 cm. of mercury pressure.

Example 1: A gas occupies 620 c.c. at a temperature of 37°C. and a pressure of 38 cm. of mercury. Change its volume to S.T.P.

$P_1 = 38$. $V_1 = 620$. $T_1 = 273 + 37 = 310°K.$

$P_2 = 76$. $V_2 = ?$. $T_2 = 273 + 0 = 273°K.$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$
$$\therefore \frac{38 \times 620}{310} = \frac{76 \times V_2}{273}$$
$$\therefore \frac{38 \times 2}{1} = \frac{76 \times V_2}{273}$$
$$\therefore 76 = \frac{76 \times V_2}{273}$$
$$\therefore 1 = \frac{V_2}{273}$$
$$V_2 = 273 \text{ c.c.}$$

Example 2: A gas occupies 1,000 c.c. at N.T.P. What will be its volume at 1,092°C. and 304 cm. pressure?

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$
$$\therefore \frac{76 \times 1{,}000}{273} = \frac{304 \times V_2}{1{,}092 + 273}$$
$$\therefore \frac{76 \times 1{,}000}{273} = \frac{304 \times V_2}{1{,}365}$$
$$\therefore \frac{1{,}000}{273} = \frac{4 \times V_2}{1{,}365}$$
$$\therefore \frac{1{,}000}{1} = \frac{4 V_2}{5}$$
$$\therefore 4 V_2 = 5{,}000$$
$$\therefore V_2 = 1{,}250 \text{ c.c.}$$

MOISTURE IN THE AIR

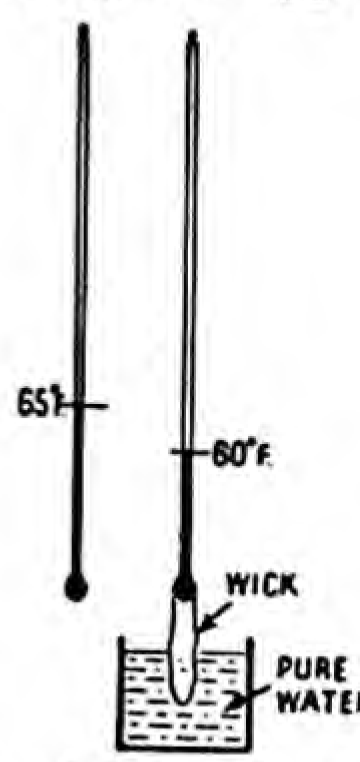
Air always contains water vapour in varying amounts. When it contains as much as possible, and can absorb no more, the air is said to be *saturated.* Hot air requires more water vapour to saturate it than cold air.

DEW. When air is cooled, a point is reached when the water vapour contained in it is enough to saturate it. If the temperature falls further, some of the water vapour must leave the air—there is now no room for it—and liquid water is deposited as *dew.* The temperature at which this happens is the *Dew Point.*

RELATIVE HUMIDITY is the amount of water vapour actually contained in the air divided by the amount required to saturate it at the same temperature. Thus the wettest possible air has a relative humidity of 1, or 100%, and perfectly dry air a relative humidity of 0.

THE WET AND DRY BULB HYGROMETER FOR MEASURING RELATIVE HUMIDITY. The dry bulb thermometer reads the air temperature. The wet bulb thermometer has a lower reading (unless the air happens to be saturated) because water evaporates into the air and takes its latent heat from the thermometer bulb. The bigger the difference, the drier the air. The relative humidity is read off from a table supplied with the instrument.

The wet and dry bulb hygrometer



For these particular values the Table says the Relative Humidity of the air is 73%.

PRESSURE IN A LIQUID

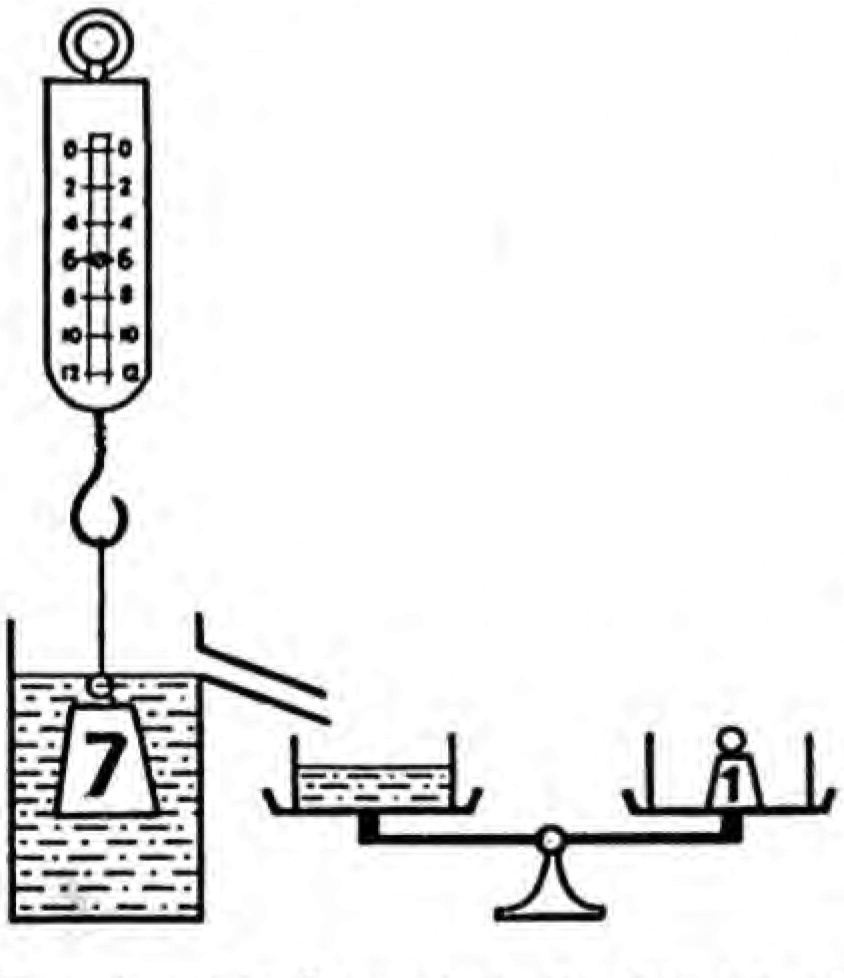
The pressure acts equally in all directions, not merely downward. The pressure at a depth of 34 ft. in water is two atmospheres, i.e. atmospheric pressure, as found at the surface, plus another atmosphere due to the pressure of 34 feet of water.

APPROXIMATE PRESSURES AT VARIOUS DEPTHS

Depth	Pressure in lb. per sq. in.	Notes
Surface	15	
34 ft.	30	
100 ft.	60	
200 ft.	105	Rubber diving suit
400 ft.	195	Metal diving suit
3,000 ft.	1,330 (over ½ ton)	Beebe's Bathysphere
2 miles	4,665 (over 2 tons)	Picard's Bathyscaphe

THE PRINCIPLE OF ARCHIMEDES. When a body is weighed in a fluid (liquid or gas) there is a loss in weight which is equal to the weight of the fluid displaced.

Example: A seven-pound weight, made of iron, is hung by a string from the hook of a spring balance and lowered into a bucket of water. As the weight goes into the water the reading of the spring balance changes from 7 lb. to 6 lb. The loss in weight = 1 lb. The size of the weight is such that it displaces 1 lb. of water.



Experiment to demonstrate the Principle of Archimedes.

The seven-pound weight weighs 6 lb. only under water ∴ loss in weight = 1 lb.

The water displaced through the side tube is collected and found to weigh 1 lb. too.

CALCULATION OF DENSITIES BY THE PRINCIPLE OF ARCHIMEDES.

Example 1: **A solid weighs 12 gm. in air and 10 gm. in water. Find its density.**

Loss in weight = 12 gm. − 10 gm. = 2 gm.

∴ weight of water displaced = 2 gm.

But 1 c.c. of water weighs 1 gm.

∴ volume of water = 2 c.c.

∴ volume of solid = 2 c.c.

$$\text{Density} = \frac{\text{mass}}{\text{volume}} = \frac{12 \text{ gm.}}{2 \text{ c.c.}} = 6 \text{ gm. per c.c.}$$

Example 2: A solid weighs 13 gm. in air, 9 gm. in water and 10 gm. in petrol. What is the density of the petrol?

Loss in weight in water = 13 gm. − 9 gm. = 4 gm.

∴ weight of water displaced = 4 gm.

∴ volume of water = volume of solid = 4 c.c.

∴ volume of petrol displaced = 4 c.c.

Loss in weight in petrol = 13 gm. − 10 gm. = 3 gm.

∴ weight of petrol displaced = 3 gm.

∴ 4 c.c. of petrol weigh 3 gm.

$$\therefore \text{density} = \frac{3 \text{ gm.}}{4 \text{ c.c.}} = \cdot 75 \text{ gm. per c.c.}$$

Example 3: A glass stopper weighs 20 gm. in water. A piece of cork, which weighs 3 gm. in air, is tied to the glass and the two weighed together *under water,* giving 11 gm. Find the specific gravity of the cork.

Weight of glass under water	= 20 gm.
Weight of glass and cork under water	= 11 gm.
∴ weight of cork under water	= −9 gm.
Weight of cork in air	= 3 gm.
Weight of cork under water	= −9 gm.
∴ loss in weight	= 12 gm.

∴ weight of water displaced by cork = 12 gm.

Since 1 c.c. of water weighs 1 gm., volume of water displaced = volume of cork = 12 c.c.

12 c.c. of cork weigh 3 gm.

$$1 \text{ c.c. of cork weighs } \frac{3}{12} \text{ gm.} = \cdot 25 \text{ gm.}$$

∴ specific gravity = ·25.

THE LAW OF FLOATING BODIES. A floating body has no downward pull upon a spring balance, so it has no weight ∴ loss in weight = full weight of the body.

By the Principle of Archimedes this is equal to the weight of the liquid displaced.

A floating body, therefore, sinks into a liquid until the volume immersed is sufficient to displace a weight of the liquid equal to the weight of the solid itself.

Example 1: A block of wood weighs 46·8 lb. and floats in water. Find the volume of wood under the water. (1 cu. ft. of water weighs 62·4 lb.).

Since the wood is floating, its weight (46·8 lb.) is equal to the weight of water displaced.

∴ 46·8 lb. of water is displaced.

Since 62·4 lb. of water occupy 1 cu. ft.,

$$46 \cdot 8 \text{ lb. of water occupy } \frac{46 \cdot 8}{62 \cdot 4} \text{ cu. ft.} = \tfrac{3}{4} \text{ cu. ft.}$$

∴ the volume of water displaced by the wood = ¾ cu. ft.

∴ the volume of wood submerged = ¾ cu. ft.

Example 2: A ship weighs 6,240 tons and passes from the sea (specific gravity = 1·03) into a fresh-water canal (specific gravity = 1). Find the volume of water it displaces (a) in the canal, (b) in the sea.

The ship displaces its own weight of water, i.e. 6,240 tons = 6,240 × 2,240 lb.

(a) 62·4 lb. of fresh water occupy 1 cu. ft.

∴ 6,240 × 2,240 lb. of fresh water occupy

$$\frac{6{,}240 \times 2{,}240}{62 \cdot 4} \text{ cu. ft.} = 224{,}000 \text{ cu. ft.}$$

(b) 1 cu. ft. of sea water weighs 62·4 × 1·03 lb.

∴ 62·4 × 1·03 lb. of sea water occupy 1 cu. ft.

∴ 6,240 × 2,240 lb. of sea water occupy

$$\frac{6{,}240 \times 2{,}240}{62 \cdot 4 \times 1 \cdot 03} = \frac{224{,}000}{1 \cdot 03} = 217{,}476 \text{ cu. ft.}$$

Example 3: The density of the ice in an iceberg is ·918 gm. per c.c., and that of the sea in which it floats is 1·02 gm. per c.c. What fraction of the iceberg is above the surface?

Let us consider a sample iceberg 1 cm. × 1 cm. × 1 cm. It weighs ·918 gm. and floats.

∴ ·918 gm. of sea water will be displaced.

$$\text{The volume of this sea water is } \frac{\cdot 918}{1 \cdot 02} \text{ c.c.} = \cdot 9 \text{ c.c.}$$

Therefore ·9 c.c. of ice must be below the water to displace ·9 c.c. of water, leaving ·1 c.c. above the surface. Thus $\frac{9}{10}$ below, and only $\frac{1}{10}$ visible above.

Lighter-than-air craft

Just as a ship floats in water because it displaces a weight of water equal to its own weight, so does a balloon or airship float in the air because it displaces a weight of air equal to the total weight of the balloon or airship. Since air itself is a very light substance, it follows that an enormous volume of it must be displaced to make up the weight of an airship, plus its passengers, engines, cargo and fuel.

Because of their great size and light construction, airships have proved themselves rather slow and liable to damage in storms; the gas usally employed to fill them, hydrogen, is very explosive in the presence of air. For these reasons, they have been discarded in favour of aeroplanes, which are known as heavier-than-air craft.

Example: The volume of an airship is 3 million cu. ft., and it is moving at a constant altitude in air of density ·07 lb. per cu ft. Calculate the total weight of the airship.

The airship displaces 3,000,000 cu. ft. of air, each weighing ·07 lb.

∴ weight of air displaced = 3,000,000 × ·07 lb.

= 210,000 lb.

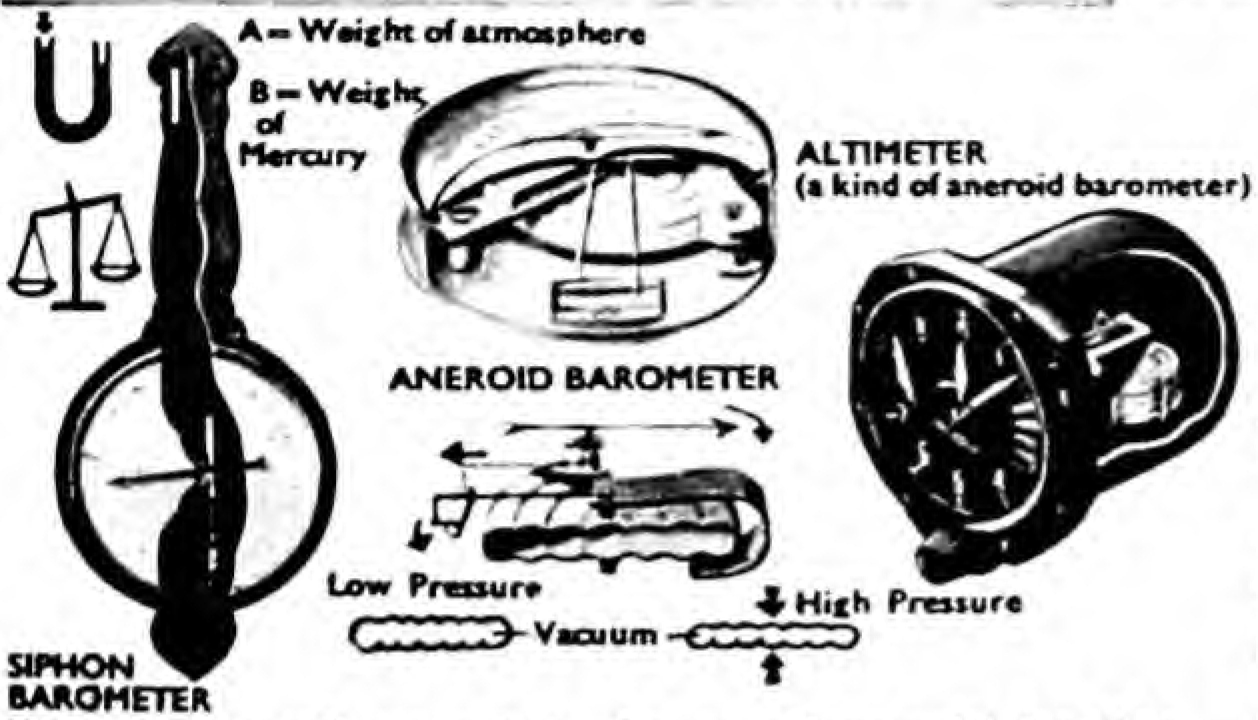
$$= \frac{210{,}000}{2{,}240} \text{ tons}$$

= 93¾ tons.

Since the airship is floating, weight of airship = weight of air displaced = 93¾ tons.

THE WEIGHT OF THE ATMOSPHERE

The air weighs down on us at 15 lbs. per sq. inch. In fact we are 'carrying' the equivalent of the weight of two buses, but we do not notice it as it is spread evenly and is the same as the pressure inside us.



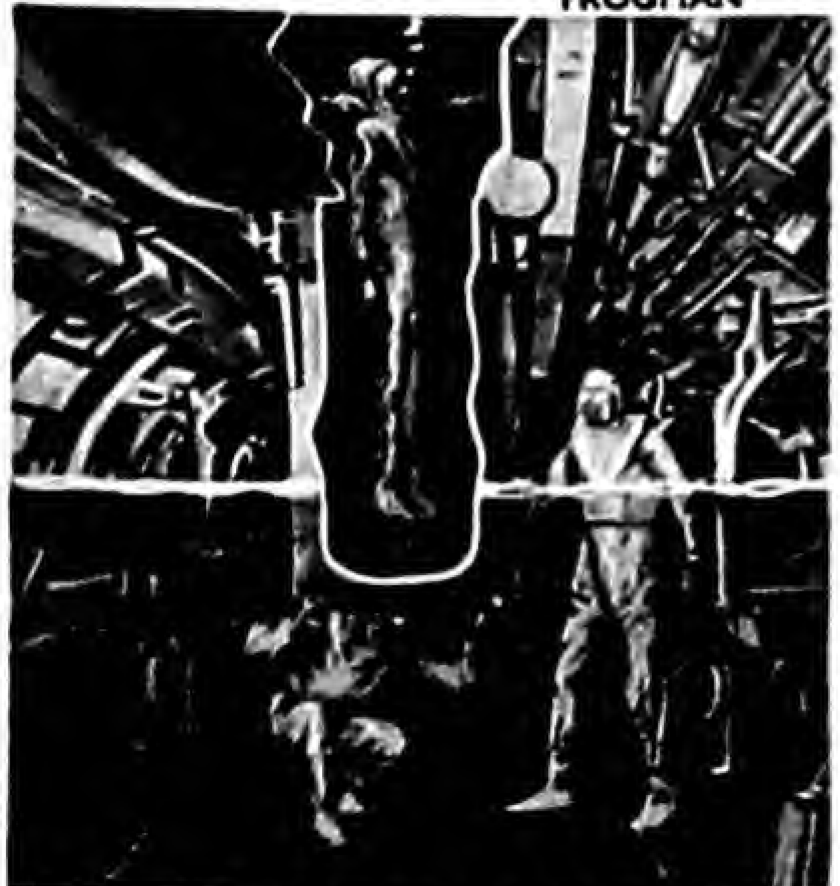
Barometers tell us what the weather will be like because they measure the weight of the air, changes of which are followed by changes in the weather.

When a pilot bales out at great heights, where air pressure is low, his pressure suit inflates to equalise the pressure outside his body with that inside.

and of the SEA

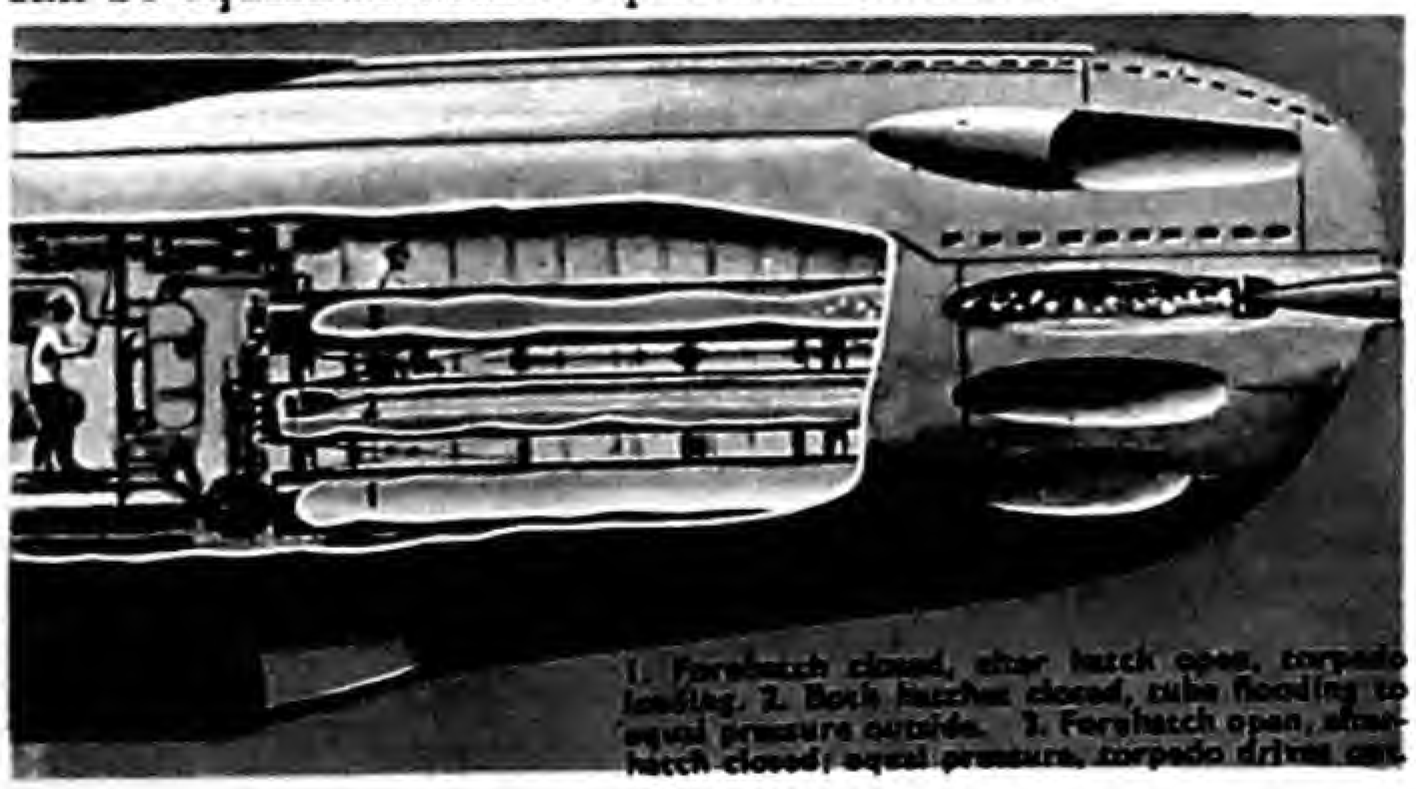
Pressure increases the further we go under the sea. Fishes have to withstand a weight of tons.

Divers protect themselves from the weight of the sea by wearing inflated clothes or by working inside thick steel housings.



Submarine escape chamber is flooded to equal pressure of sea outside. High pressure air blows out of men's lungs as they float to lower pressure with mouths open.

Torpedo tubes are an example of an air lock whose pressure can be equalised with the pressure either side.

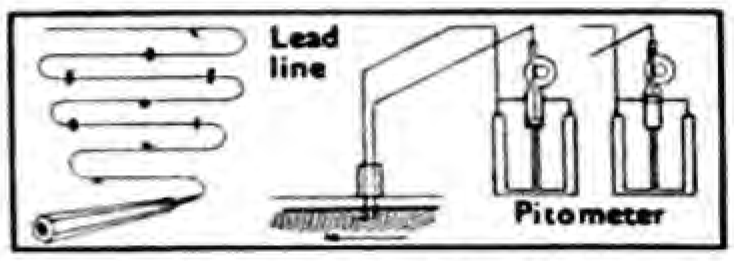


THE NAVIGATOR'S WORK

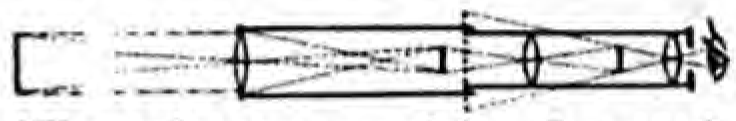
His Instruments

In navigation at sea, it is vital to know the correct time according to Greenwich, because all bearings taken from stars are subject to variations depending on the time of day or night. For this reason the ship's chronometer is one of the navigator's most important instruments. The Radio enables him to check Greenwich mean time, as well as getting cross bearings from radio shore stations with a direction finding loop aerial. The compass gives magnetic north, and all bearings are measured by the degrees marked on its card from centre line of ship. The sextant measures heights above the horizon. *See also* THE ASTRONOMER AT WORK

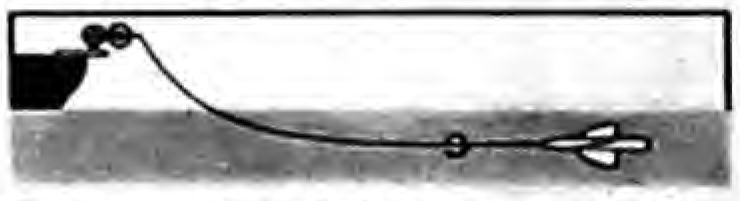
The gyro compass is not magnetic, it is a freely suspended fly-wheel-like top kept spinning by electricity. Because the earth itself is rotating from west to east the flywheel takes up a position parallel to the lines of latitude "sitting" in a position of equilibrium with the earth's motion, and therefore its spindle always points N and S.



Close to shore the lead line is dropped overboard and runs out until it touches bottom. Markers show depth. The pitometer records the ship's speed, as the pressure increases, in the tube beneath the hull.



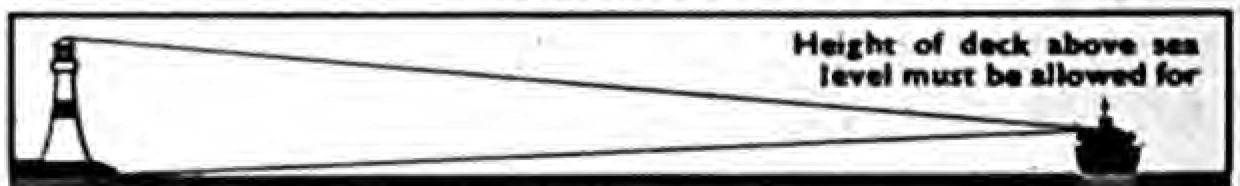
The telescope enables the navigator to see an enlarged view of distant objects. (*See pages* 118, 119.)



Log. A miniature propeller pulled after the ship. Its rate of spin gives speed and dials worked by gears show the distance run through the water.

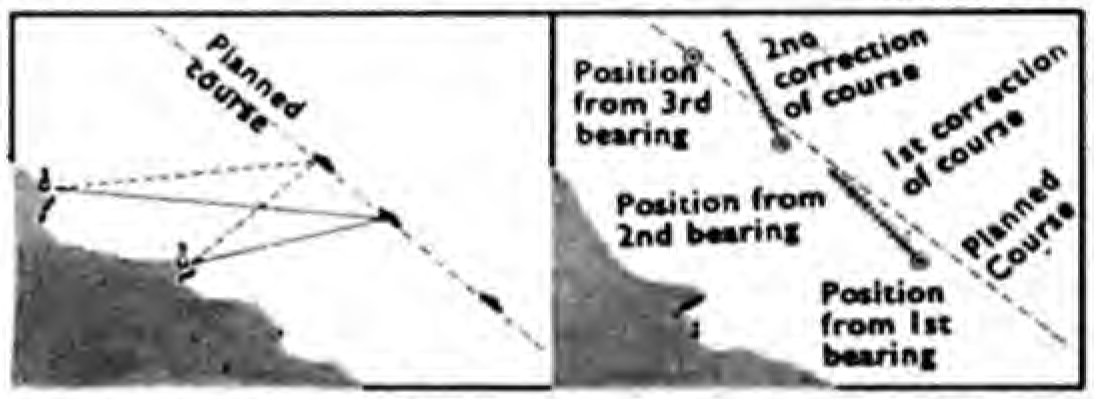
Pilotage Close to Land

The most dangerous time for ships is when they are sailing close to the shore for currents could easily take them off course and into danger. Thus a navigator needs to make continuous checks of his distance from the shore.

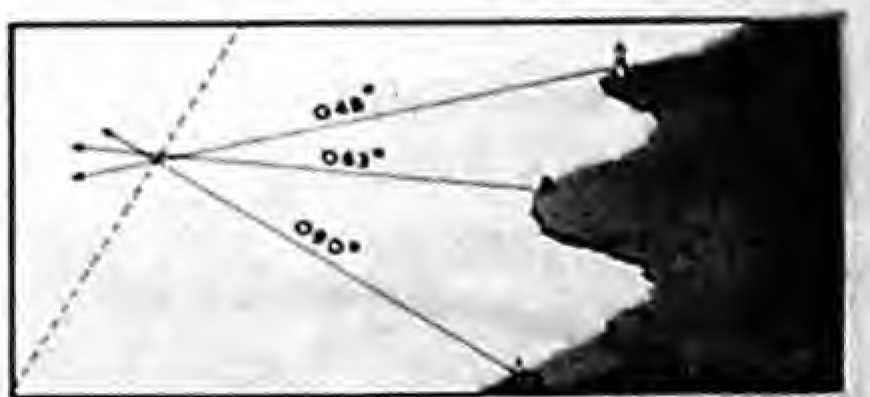


If the height of a visible point, such as a lighthouse, is known, and the angle between its top and sea level is measured by a sextant, the distance from it can be worked out

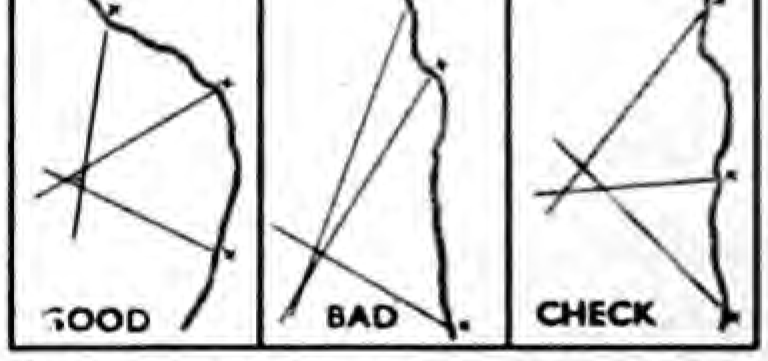
V-shaped sights and prism mirror show point and compass bearing at the same time.



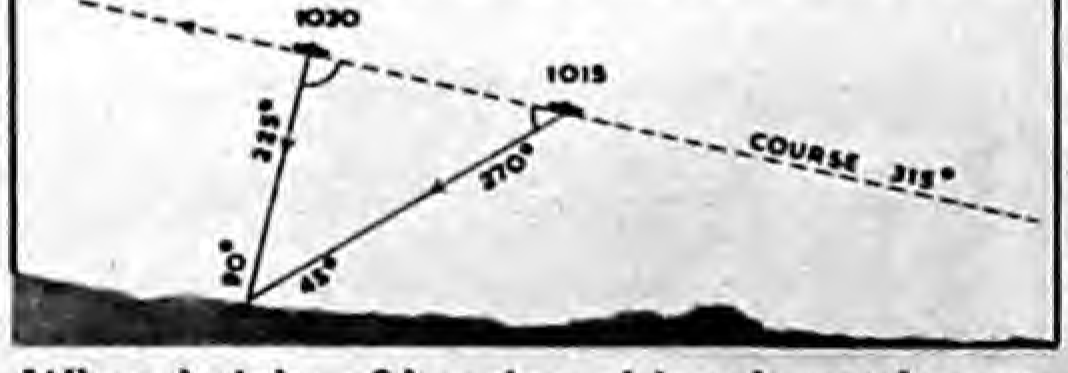
If the bearings of two known points are taken at intervals on an azimuth ring, the navigator can check whether currents have deflected ship from planned course and whether correction has been sufficient to bring her back on course.



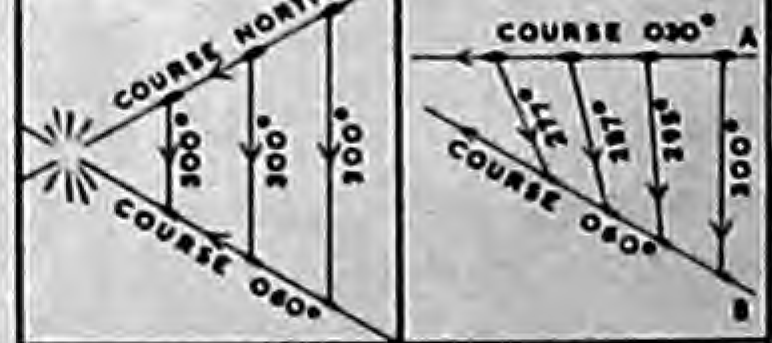
Minor inaccuracies in taking bearings on three points mean they almost always form a " cocked hat ". If cocked hat is nearly equal-sided, it is safe to assume ship is in centre.



Centre picture shows how a tiny inaccuracy when bearing points are too close cause an acute angled "cocked hat" that is obviously wrong. Needs checking



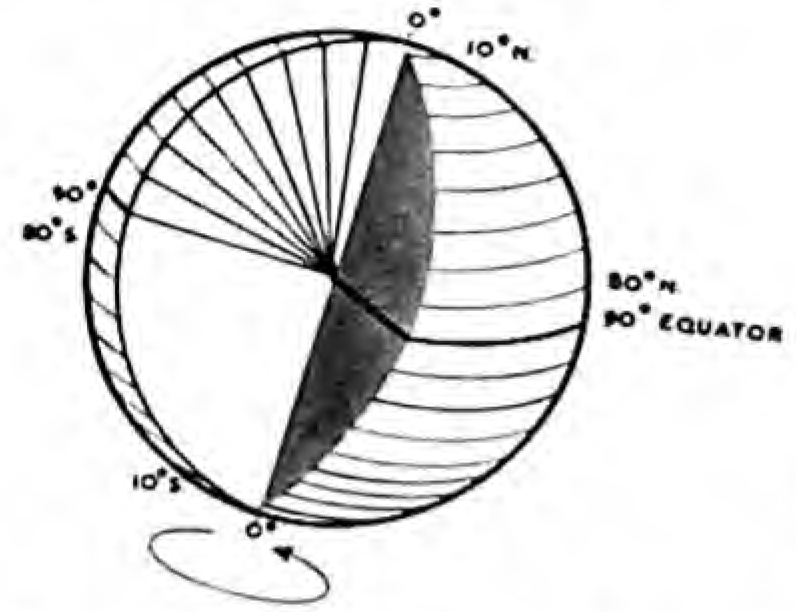
When height of bearing object is not known, record the time when it is 45° off the bow and again when it is at 90°. The distance run equals the distance from the shore because the triangle is right angled.



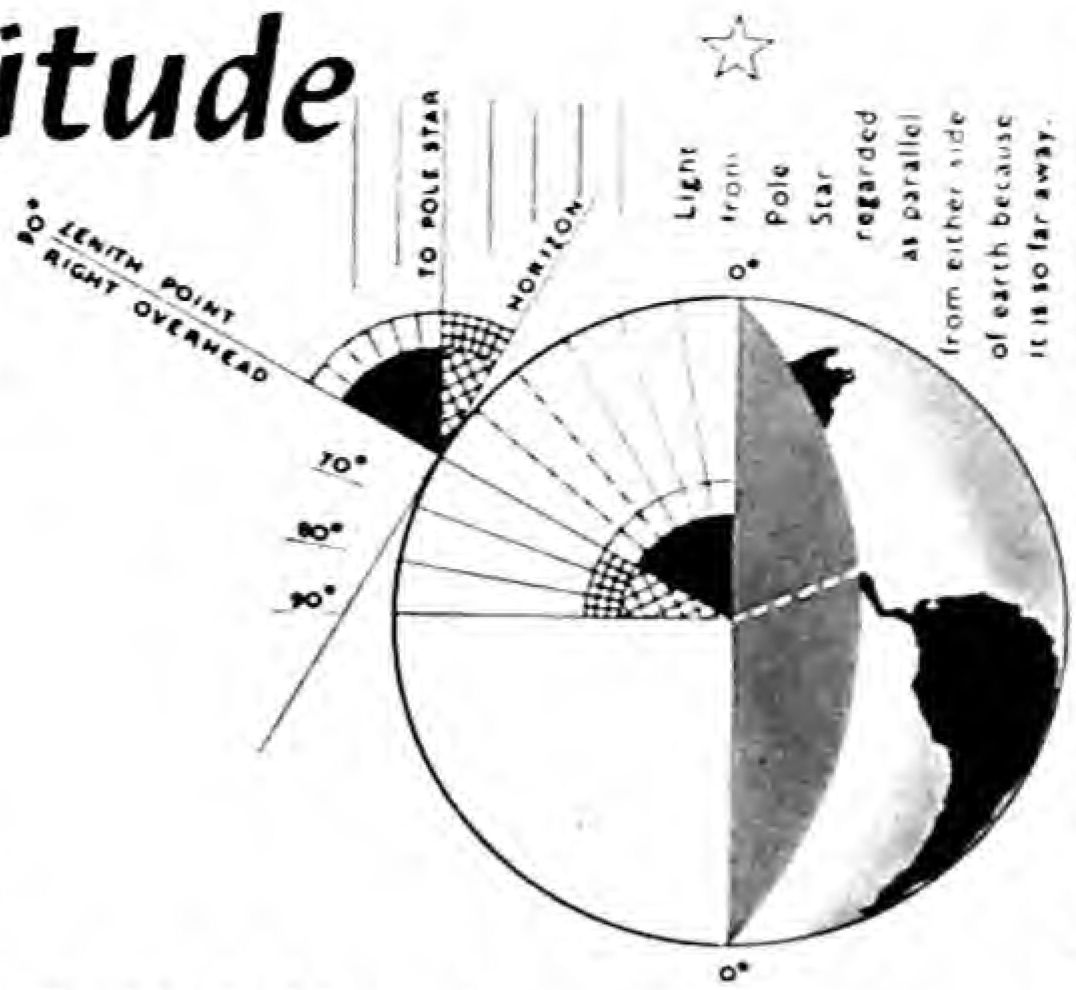
Constant bearing means collision ; decreasing bearing means ship A is sailing faster and will pass course intersection ahead of B.

Finding Latitude

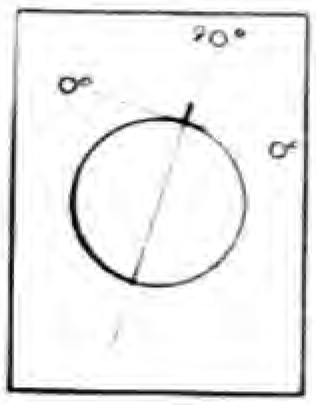
To check his position when out of sight of land, the navigator must depend on calculations based on the angle at which he sees the sun, stars, or planets.



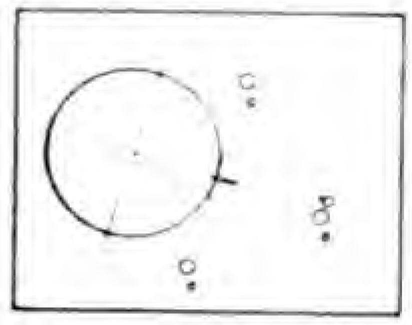
Lines of latitude are divisions of the circle from the centre of the globe out to its circumference. The axis is zero.



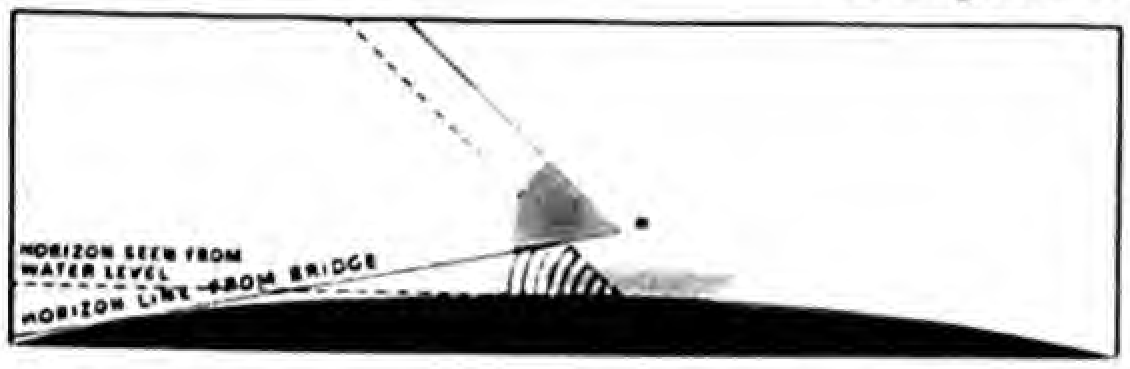
The blacked in angles must be equal because they are made by a line cutting two parallel lines. With each of the shaded angles added they become right angles (90°). It follows that the shaded angles also are equal. The angle above the horizon made by the pole star subtracted from 90° gives the number of degrees of latitude.



It becomes even more obvious if an explorer is standing right on the North Pole. He would see the Pole Star right overhead (his zenith) at 90° to the horizon. And 90° - 90° = 0°, the latitude of the North Pole.

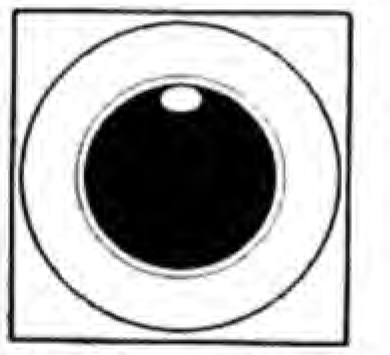


On the equator the same man would see the Pole Star right on his horizon, that is at 0°. Take 0° away from 90° = 90°, which is the latitude of the equator. Knowing his latitude the navigator knows that he is somewhere on an imaginary circle girdling the earth.



A very important correction the navigator must make to his sextant reading of the Pole Star's angle above the horizon, is the error caused by his height above the sea. Special tables are used for this. The same thing applies to all star observations.

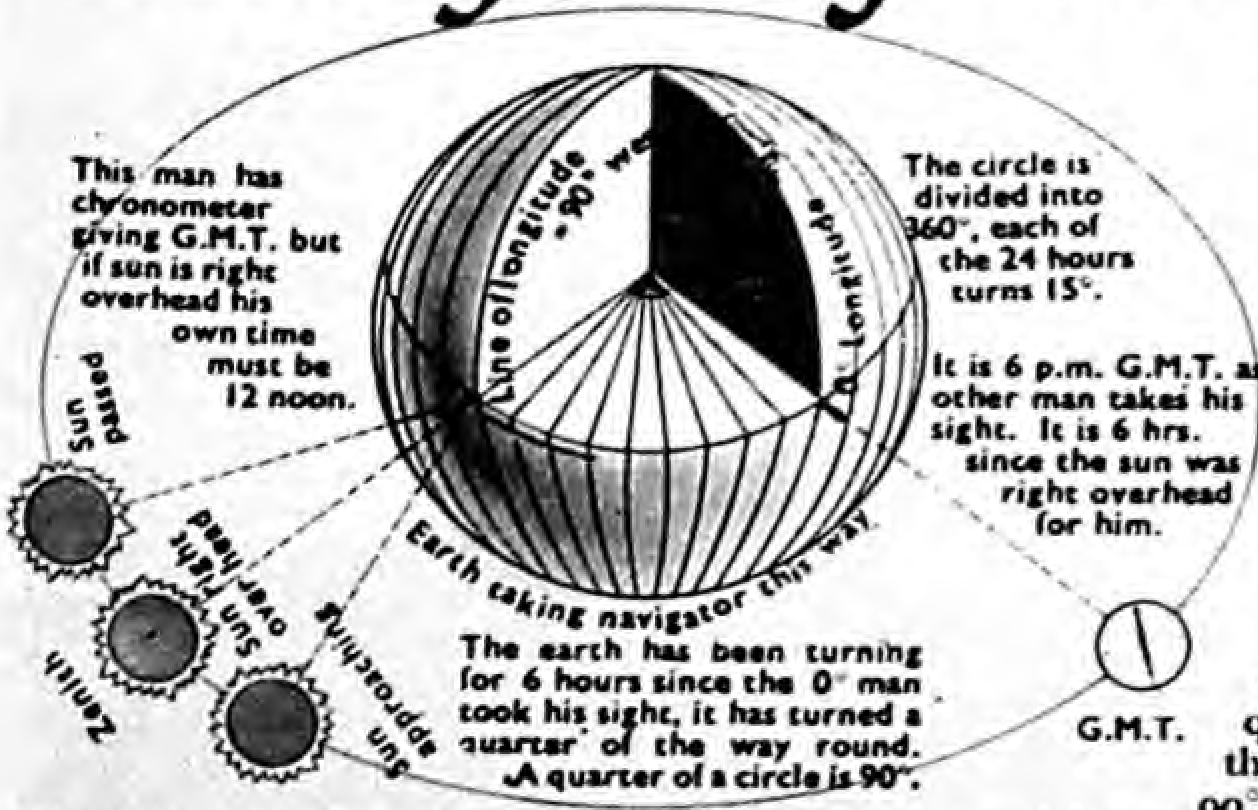
NAVIGATOR USING SEXTANT



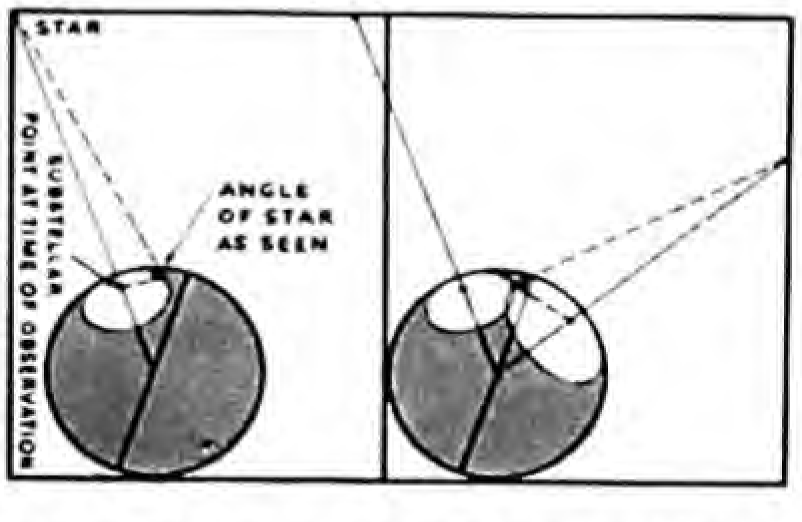
BUBBLE IN SPIRIT LEVEL

Navigators of aircraft often are unable to see a horizon so their sextants are fitted with a spirit level in which the bubble is at the centre when the sextant is horizontal. Of course this is not so accurate and many sights are taken and averaged out.

Finding Longitude

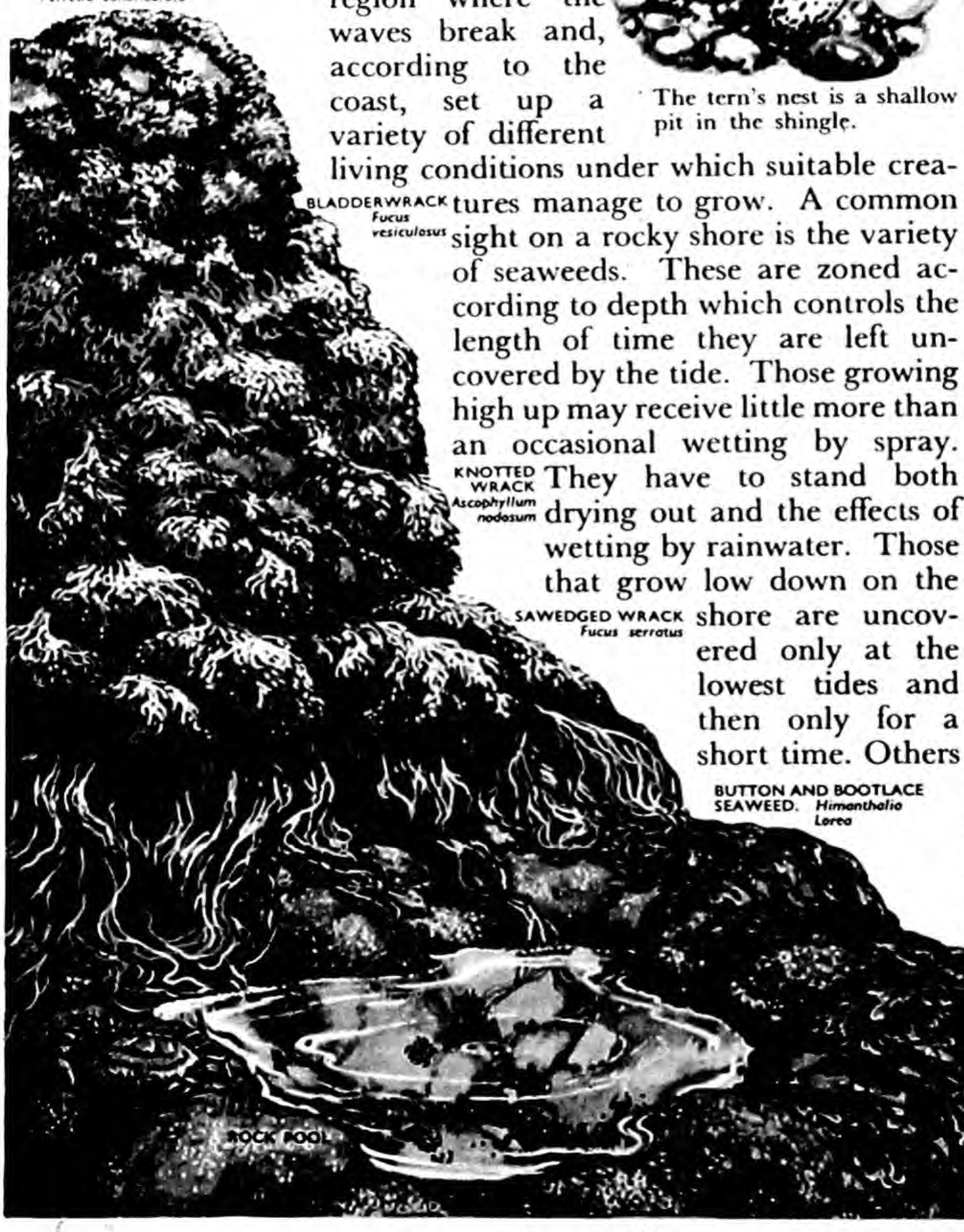


Lines of longitude divide the earth N. and S. all round the equator (360°). The Sun is the best of all "fixes". It is 12 noon local time when the sun is at its highest point (not necessarily right overhead because of the tilt of the earth, *see page* 159) when seen by the navigator. But he has a chronometer which says that it is 6 p.m. at Greenwich at that moment because the earth has been turning for six hours since the man at 0° longitude took his sight. The earth has turned a quarter of the way round. A quarter of a circle is 90°, so the navigator's longitude is 90° west. Because of the earth's spin it is more difficult to find longitude from star sights because the angle of any star will depend on the time. The starting point on the earth from which stars are measured is Greenwich called 0° Longitude; and in the sky the starting point is the first star in the constellation Aries right overhead. Because the earth takes 24 hours to rotate on its axis, the angles measured are called Sidereal (Star) Hour Angles.



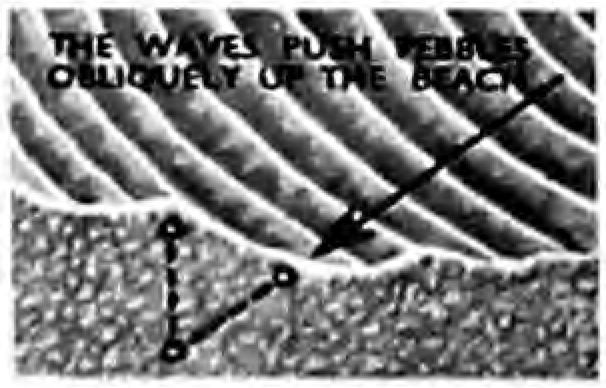
Just as at the N. Pole the Pole Star is right overhead, so there must be a place on the earth's surface where each of the other stars is right overhead at any one moment. Tables give these positions for all hours. By measuring the angle at which the star is seen the navigator can work out the distance he must be from the substellar point. He is somewhere on a circle of that radius drawn round it. A sight on a second star gives him another position circle which overlaps the first. This leaves him with only two possible positions, one of which he will know to be correct.

The Sea Shore



The shore is the region where the waves break and, according to the coast, set up a variety of different living conditions under which suitable creatures manage to grow. A common sight on a rocky shore is the variety of seaweeds. These are zoned according to depth which controls the length of time they are left uncovered by the tide. Those growing high up may receive little more than an occasional wetting by spray. They have to stand both drying out and the effects of wetting by rainwater. Those that grow low down on the shore are uncovered only at the lowest tides and then only for a short time. Others

The tern's nest is a shallow pit in the shingle.

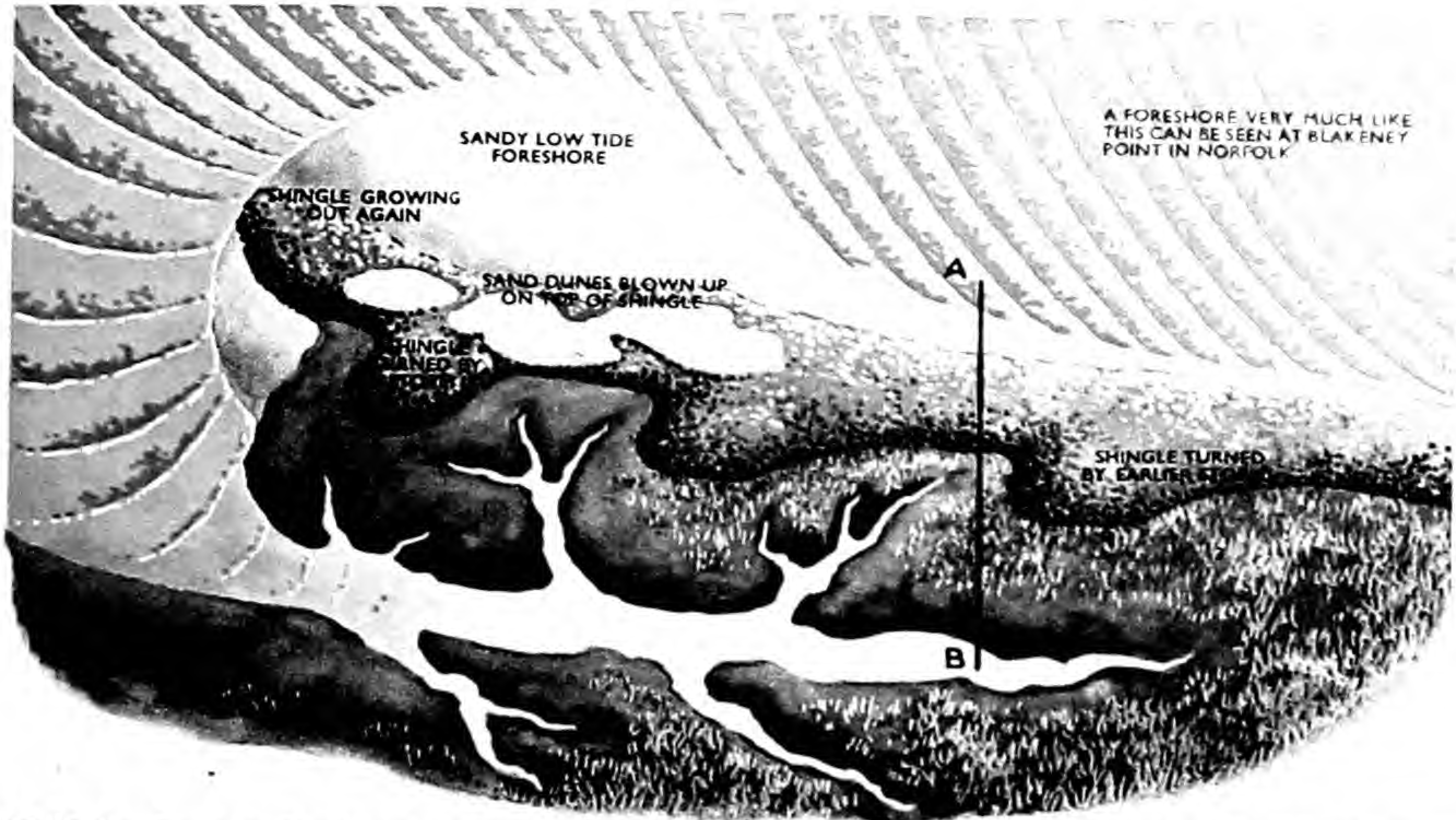


Rolling down in the backwash they finish up further along the shore.

Cross section of the beach shown above. Different levels mark old storms.

At low tide strong winds may blow sand up over the shingle to form dunes.

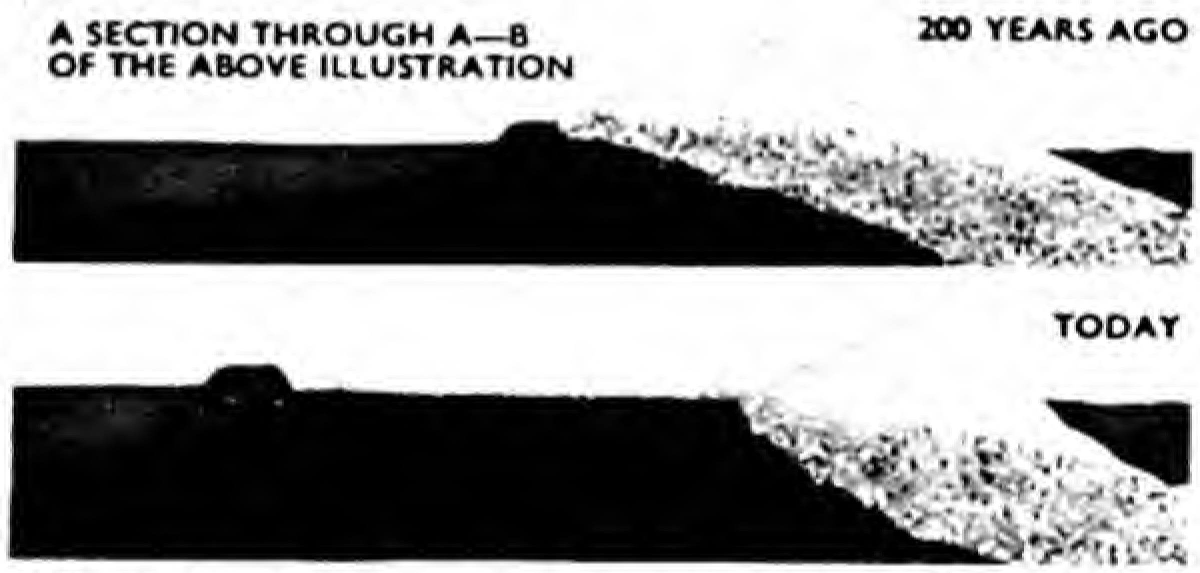
A muddy foreshore with inland tidal creeks and saltmarsh plants.



Muddy foreshores are found only in sheltered places. They are continually being built up by the tide which brings in silt. This it deposits as it turns to ebb. After a number of years a marsh develops as sea plants take root.

are never uncovered at all and some are submerged so deeply that only feeble sunlight reaches them.

Waves usually break at an angle to the shore though in shallow water the drag of the shore makes them swing round to be more nearly parallel with it. There are several types of shoreland. The shingle one which is constantly moving, the muddy, which is always growing, and the sandy.



When the marsh is grown up man builds a bank to shut out the tide and cultivates the land.

In the area (1) in the large illustration sea birds and waders may be seen.

At (2) sea lavender may grow and rabbits sometimes venture to browse.

(3) is covered by salt plants, such as scurvy grass, and is grazed.

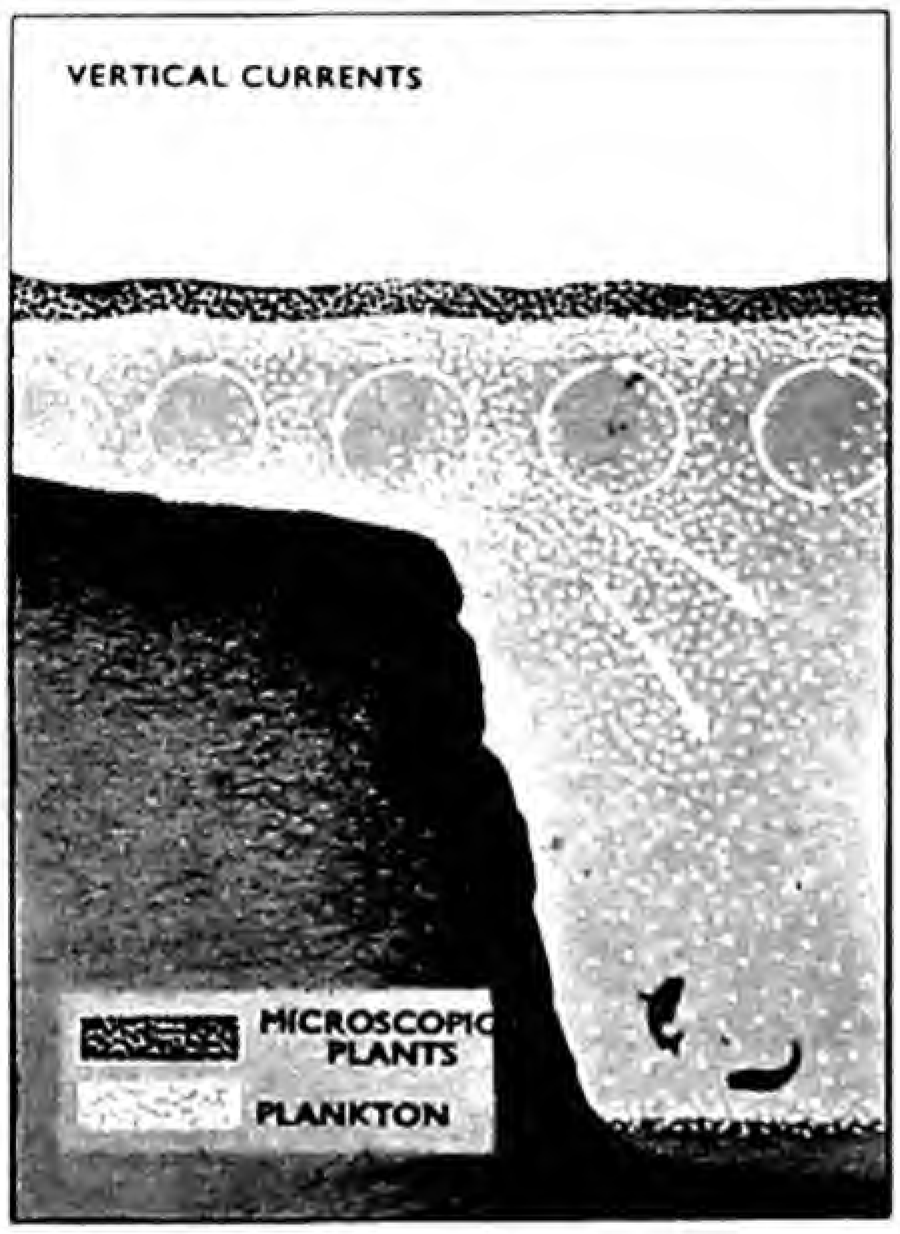
Showing how, in history, land was reclaimed around the Wash.

Ocean Currents

In addition to the tidal current, which is a wave, the surface of the sea has horizontal currents known as drifts. Vertical currents also develop between the sea floor and the surface. The drifts are induced by wind and the rotation of the earth's surface. Well known ones are the warm Gulf Stream and the cold Labrador Current.

High tide at same time on each line.

Vertical currents are caused by differences of temperature produced by the heat of the sun. Sun warmed water rises carrying to the surface minerals set free by decayed animals.



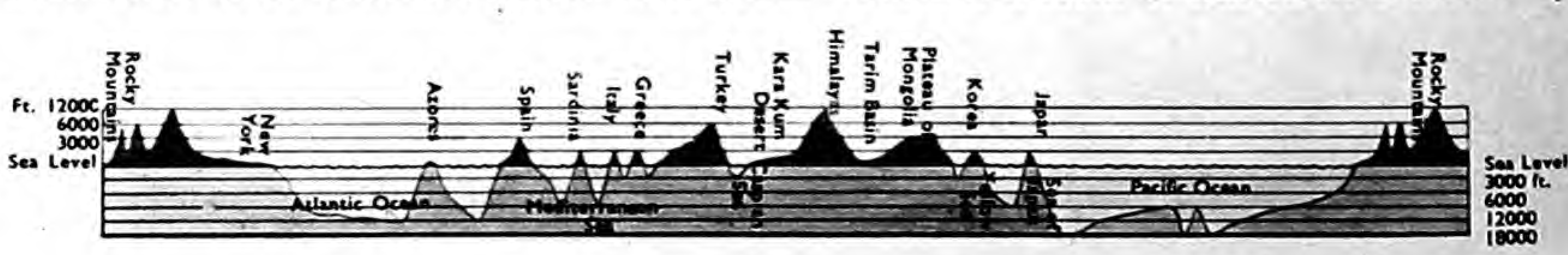
When fish die minerals freed by decay rise to the surface waters. Microscopic plants absorb them for growth. These plants are then eaten by fishes. The cycle is repeated indefinitely.

This shows the main courses of hot and cold currents. Water on the same latitude can differ considerably in temperature.

The Ocean Floor

During the formation of the earth, great continents appeared and rifts developed giving us the land with its great mountains and ocean deeps. Deep beneath the sea the continents are still joined by land. Small islands off continents are often the tops of mountains now submerged.

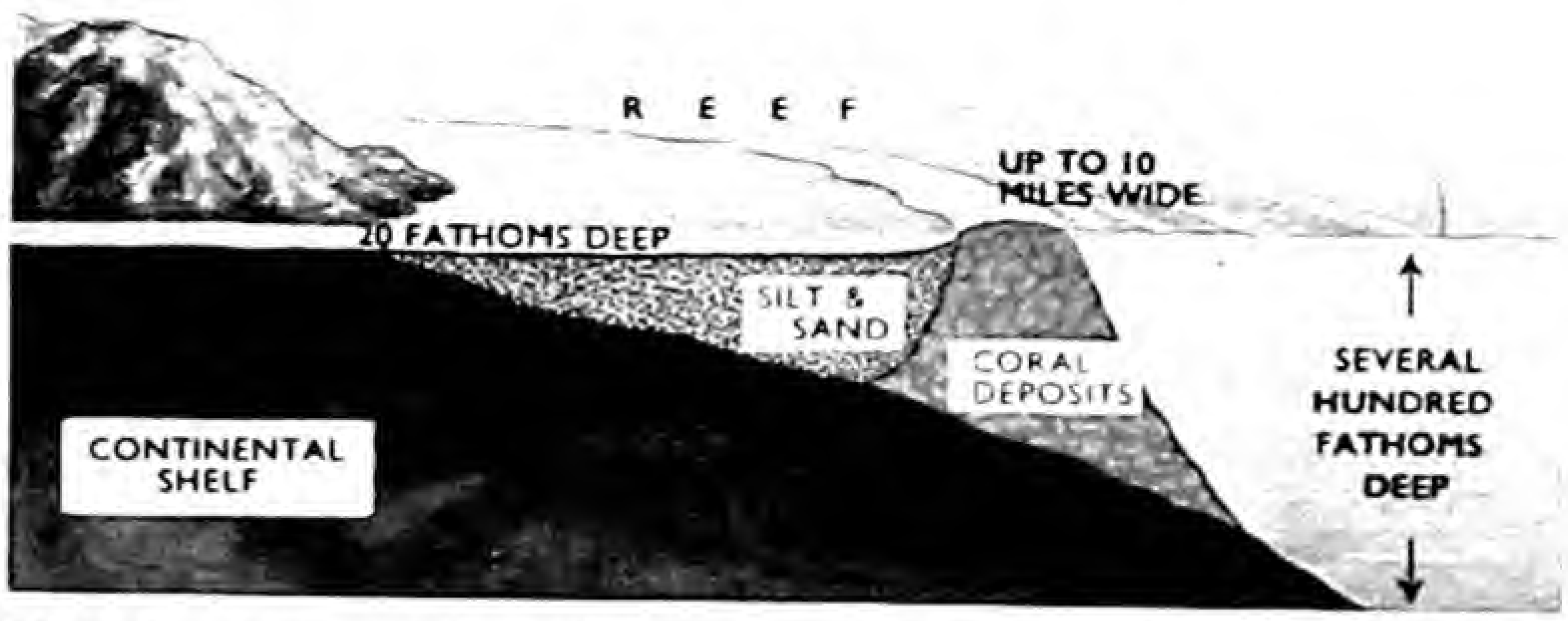
In regions where the sun warms very shallow, clear water tiny creatures called polyps have constructed enormous colonies of coral. Coral is a form of limestone secreted by



these polyps where they sit. The polyps can grow upon the remains of previous generations, gradually rising higher and higher until they nearly reach the surface of the sea. Broken dead coral is then thrown up into beaches by the seas' waves.

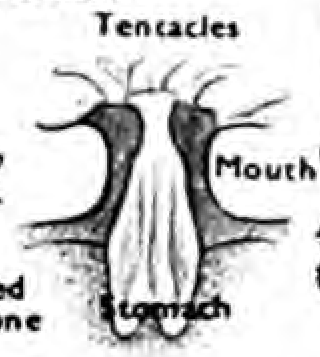
This may produce an off shore reef running for great distances along the coast of a continent. A fine example of this is the Great Barrier Reef of Australia.

In other cases the fringing coral reefs seem to have developed around the tops of submerged mountains. As they grow they produce circular coral atolls.



Here is a cross section of a barrier reef showing the sloping sea bed and the great thickness of the coral deposit.

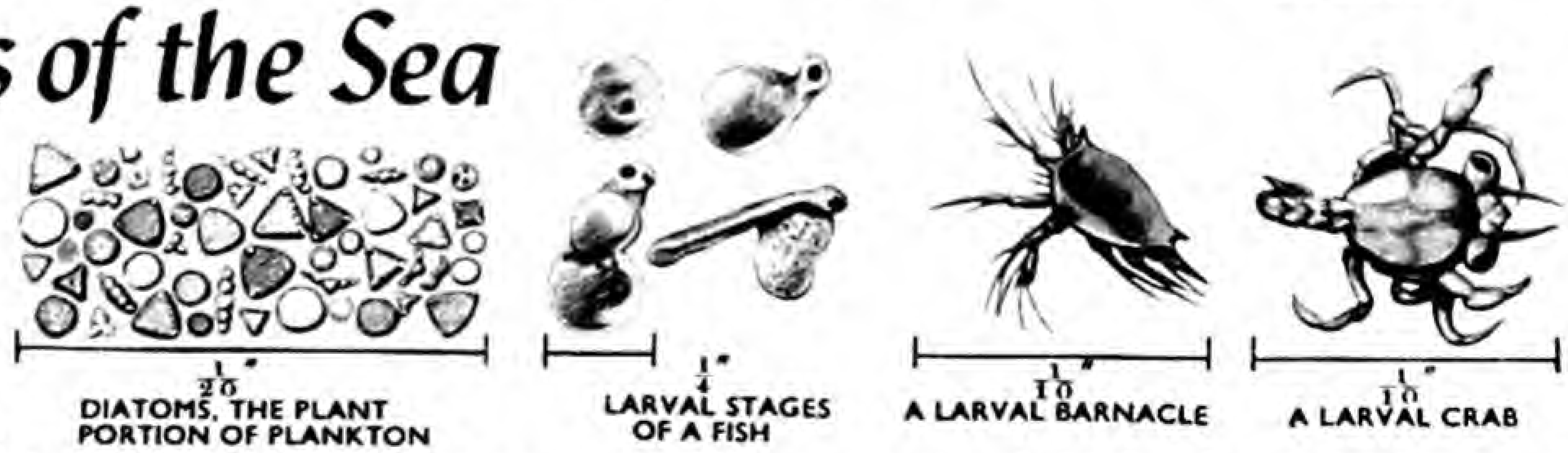
A coral atoll develops in much the same way. The lagoon within the barrier gradually traps silt until it is quite shallow.



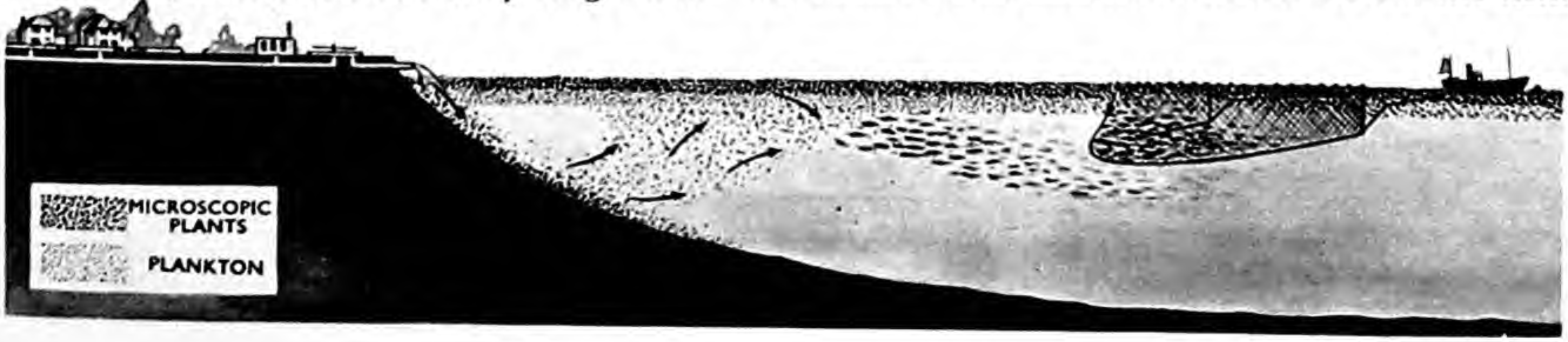
The coral polyp lives in colonies, it is soft bodied and feeds by tentacles.

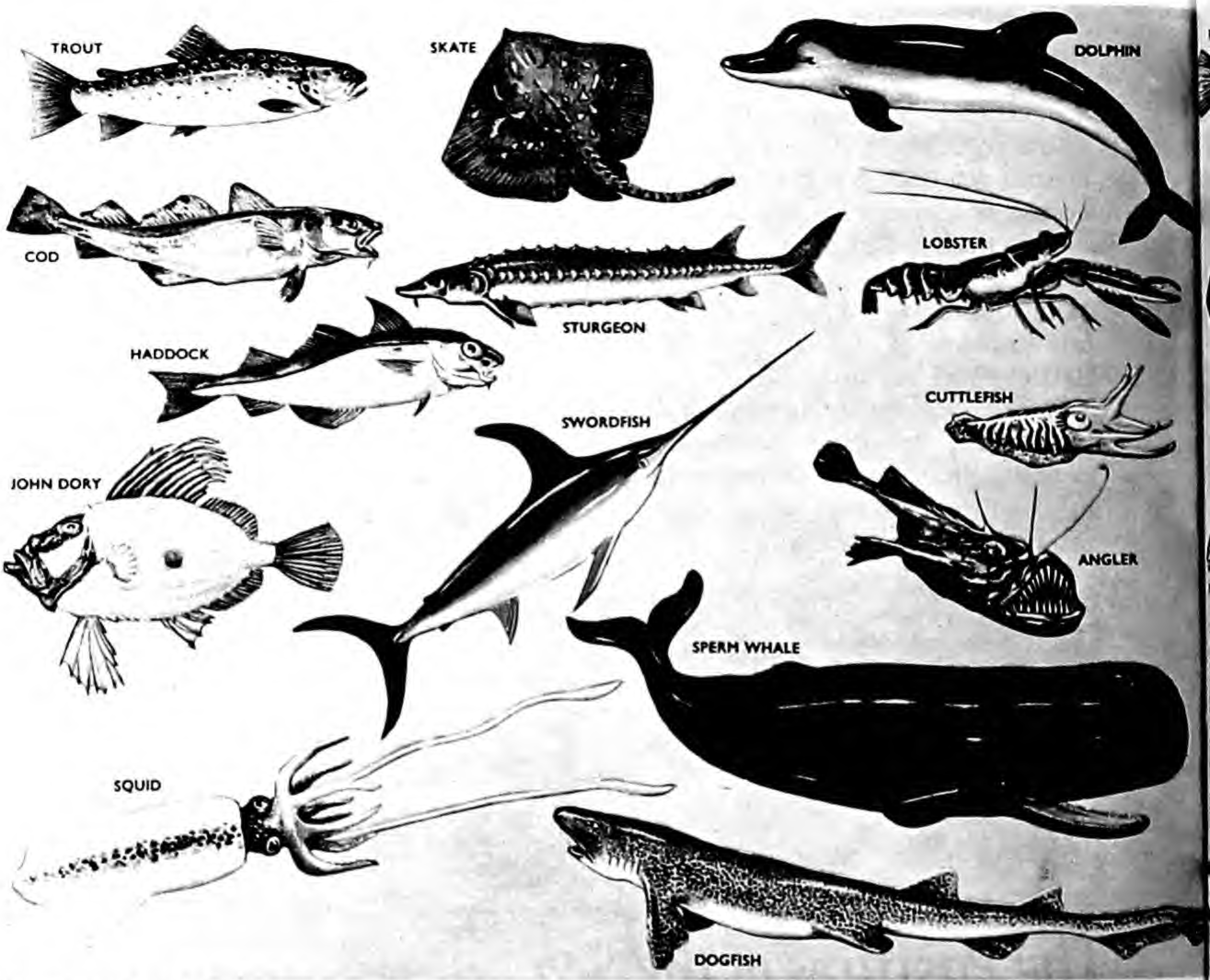
TYPES OF CORAL

The Pastures of the Sea

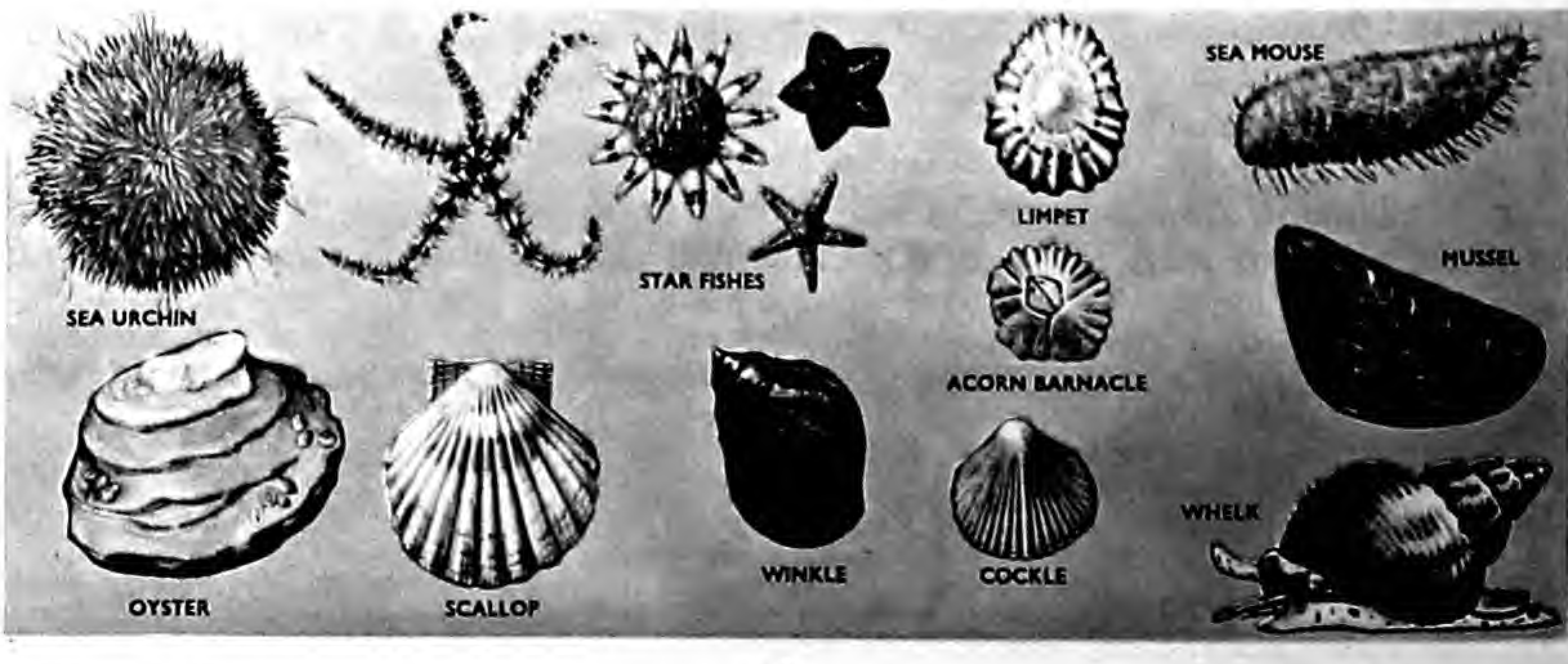


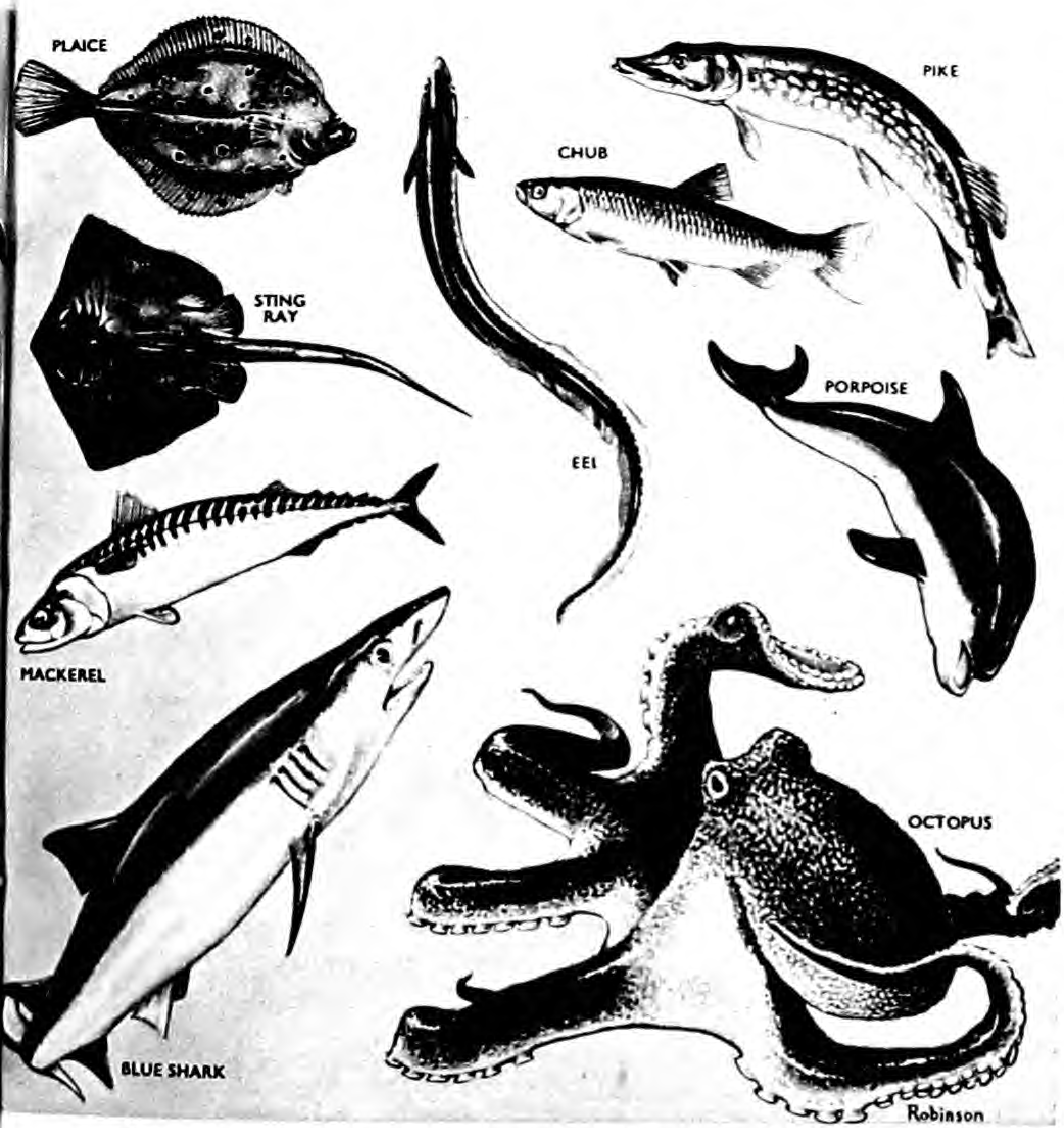
Sewage is piped into the sea and decomposes. Minerals rise and are absorbed by microscopic plants. These are eaten by plankton animals of the surface water. Plankton contains the larval stages of creatures, which are eaten by larger fish. This food chain continues when we eat the fish.



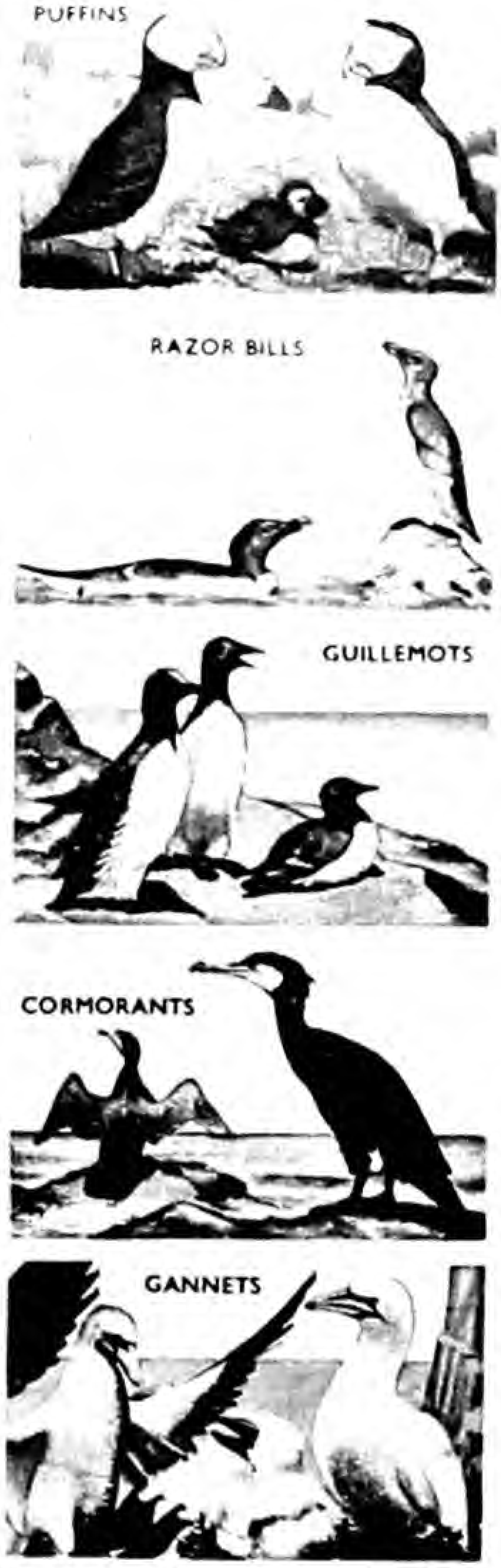


Above are a few of the enormous variety of sea creatures to be found. The chub and pike are freshwater fish. Not all fish are suitable for food, sometimes it is the by-products, like oil from the whale, which are valuable.

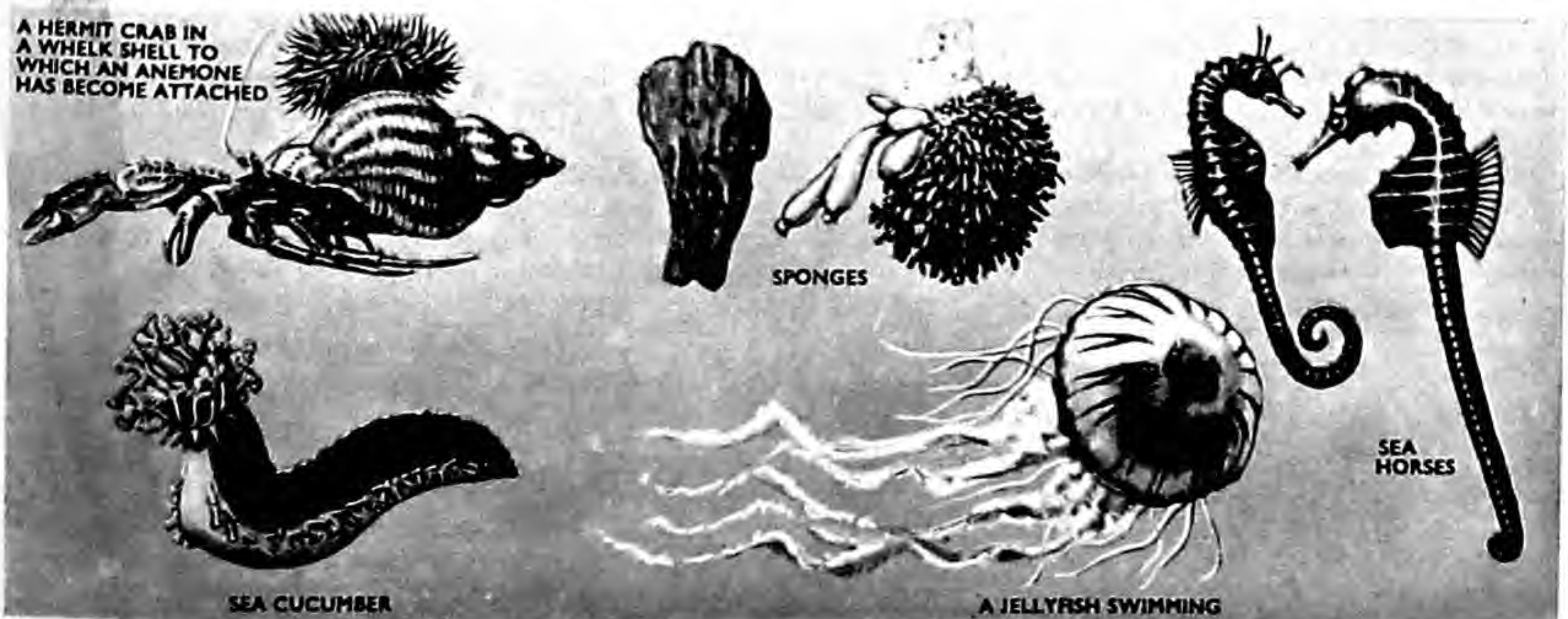




These creatures are not shown to scale. The whale when full grown may be ninety feet long, the chub no more than ten inches.

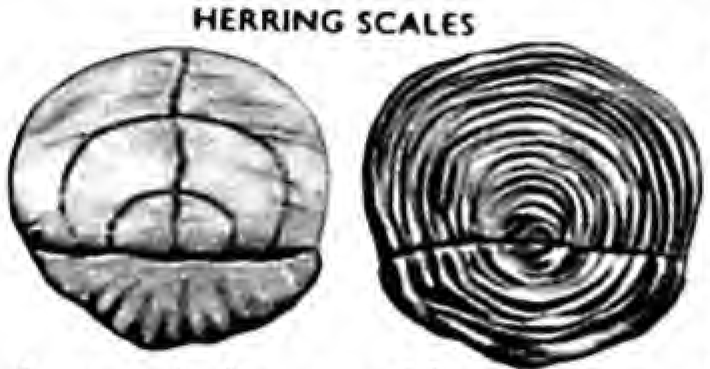


These birds are cliff dwellers and fish is their staple food



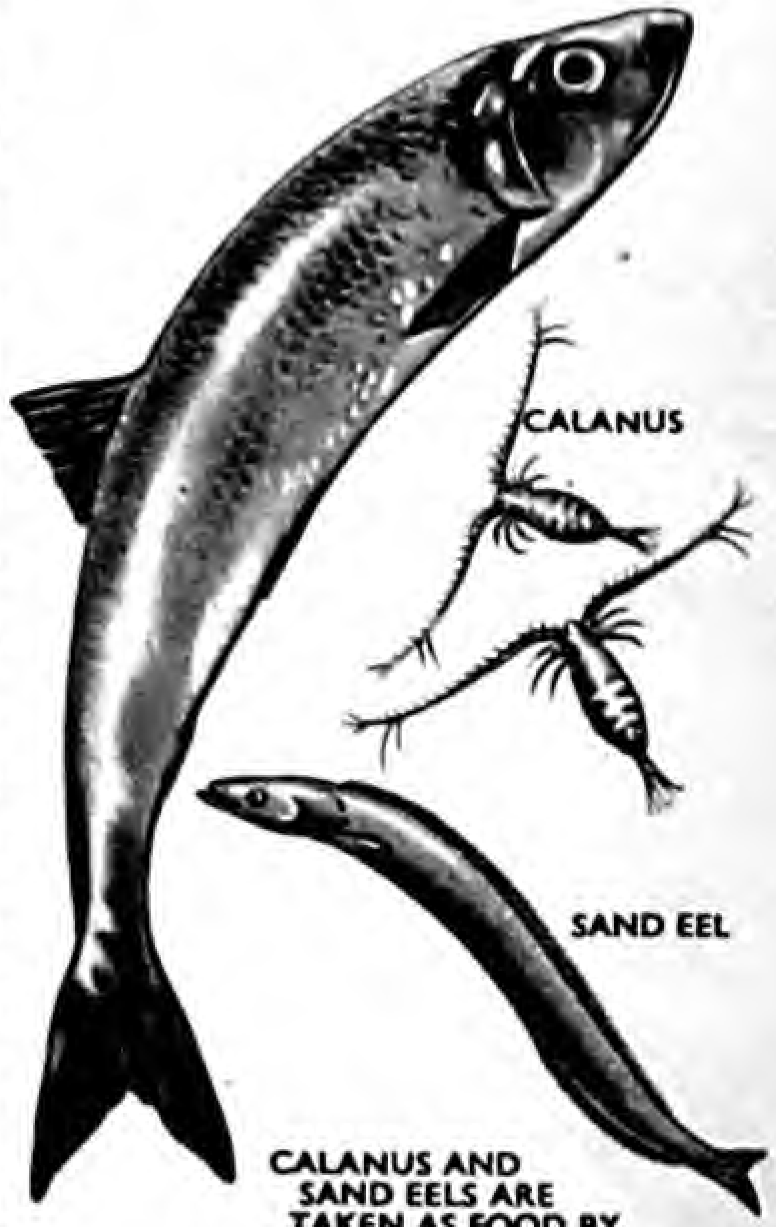
The Life of a Herring

The herring is the most valuable food fish caught off European coasts. From an egg laid on the sea floor in shallow water it hatches into a small eel-like creature. At one year old it is sold by fishmongers under the name of "whitebait". Eventually it develops into the familiar adult. It feeds by taking water into the mouth and forcing it out over the gill rakers which retain the plankton. The herring also eats small worms, small fish and spawn. At the same time the oxygen dissolved in the water is absorbed by the blood in the gills.



Age and change of food show as dark circles. The scale on the left shows an age of three years.

A curious fish associated with the herring is the chimaera called by fishermen "The King of the Herring". They say that where these fish are swimming there will also be shoals of herring.



CALANUS AND SAND EELS ARE TAKEN AS FOOD BY THE ADULT HERRING

Fishermen and their Methods

A trawler drags a net along the sea bottom. Otter boards keep the mouth of it open. By pulling the net through the water the fish are swept in and forced to the "cod-end".

Near deep rocky shores fishermen lower baited lobster pots into the sea. The lobsters enter the pots, consume the bait and are then unable to get out of the trap.

Cod is fished over the banks of Canada and Greenland from dories which sail long distances from a mother ship.

Oysters are grown by placing "spat" on sea beds prepared with rubble on which the oysters settle. Each year beds are fished for mature specimens.

A drifter pays out a buoyed net, sometimes two or three miles in length, which is weighted at the lower end and hangs vertically in the water. The fish are caught in it by the gills.

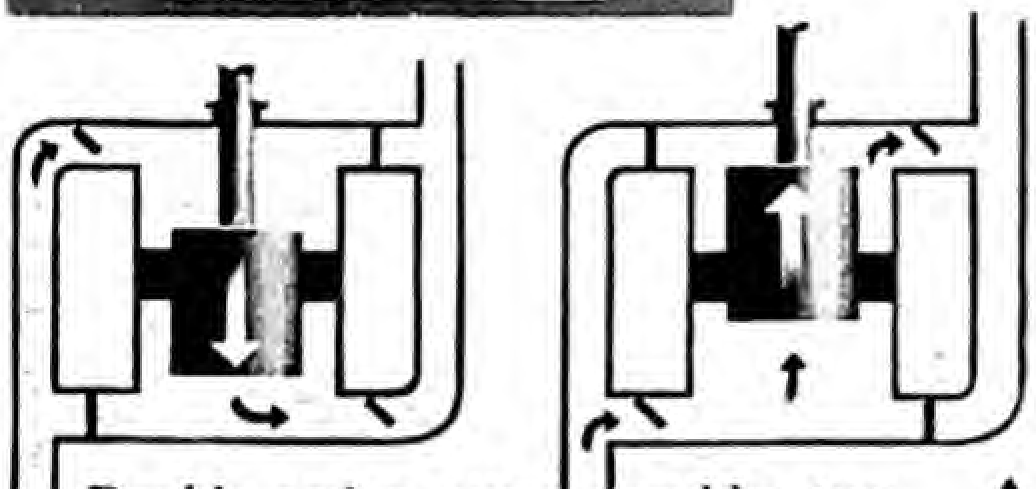
PUMPS

The simple lift pump showing the upstroke.

Downstroke will force water now being pulled up by piston through valves.

Pumps which work by suction have one thing in common—their ability to create a vacuum above the liquid or gas that has to be lifted. Once the vacuum has been made the pressure of the atmosphere on the rest of the liquid or gas will push it up into the pump to counteract the vacuum. Most piston pumps have valves to allow water to pass above the piston on the downstroke, and be bodily lifted as the next upstroke creates a new vacuum below the piston. Like the syringe the forcepump has no valve in its piston, but a valve elsewhere allows the liquid to bypass its piston so that atmospheric pressure raises it to a height. The vanes of rotary pump gears or propellers act as pistons when above the level of the liquid they are pumping (suction) but if they are below the level they are simply devices for *pushing* the liquid mechanically.

If the level of water falls in this well, the rotary pump will pump it as long as it does not fall lower than 30 feet below its own position.



Double action pump provides two routes for liquid at each stroke.

Hypodermic syringe is a pump without a valve. When the piston is moved down the liquid will be forced out again.

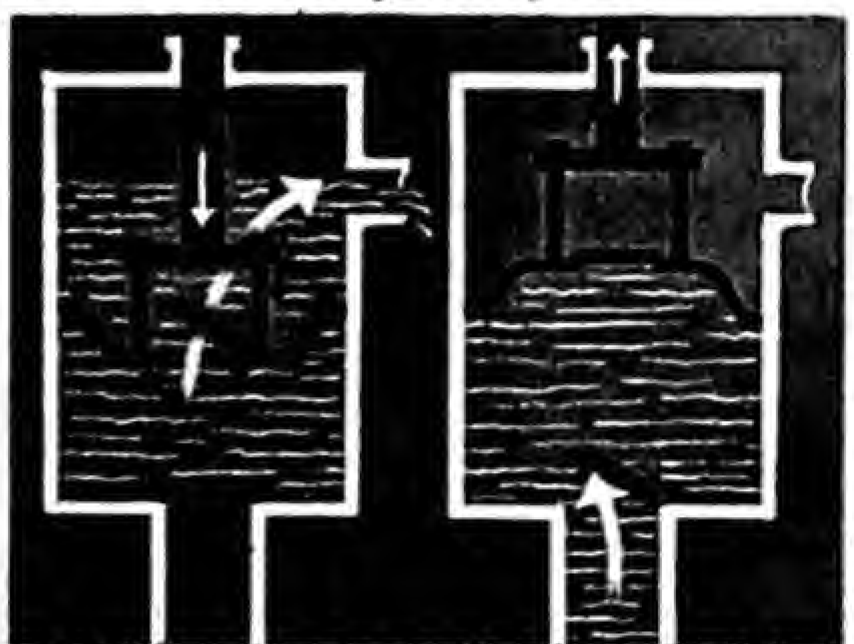
A pump can only lift water up as far as atmospheric pressure will balance it — about 30 feet in practice. For a 34 foot column of water weighs as much as a column of the atmosphere of the same width

Centrifugal pump, eccentrically mounted in chamber has anchor shaped paddles which fly out to pull water at one side.

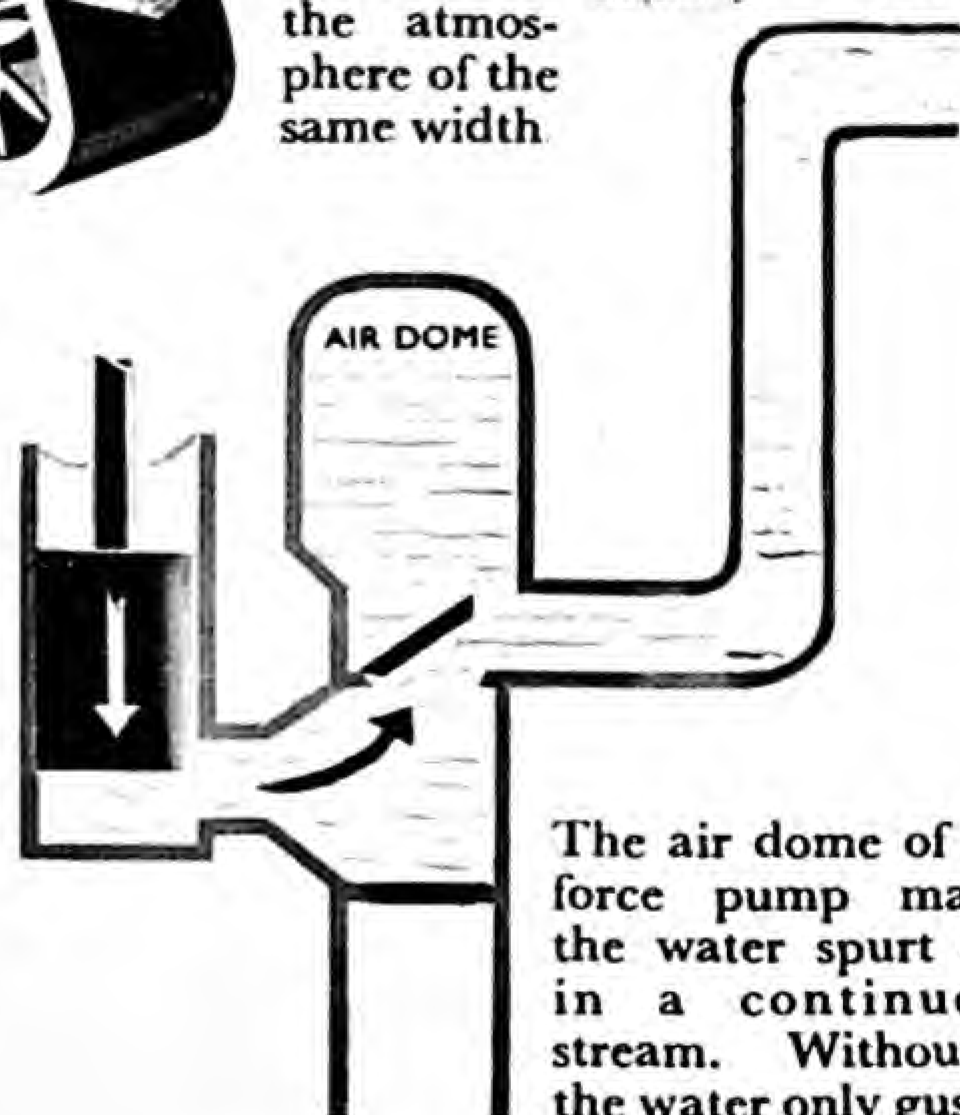
Semi-rotary pump gets double action from seesaw movement of centre piston plate.

Rotary pump gears can act as pistons (below).

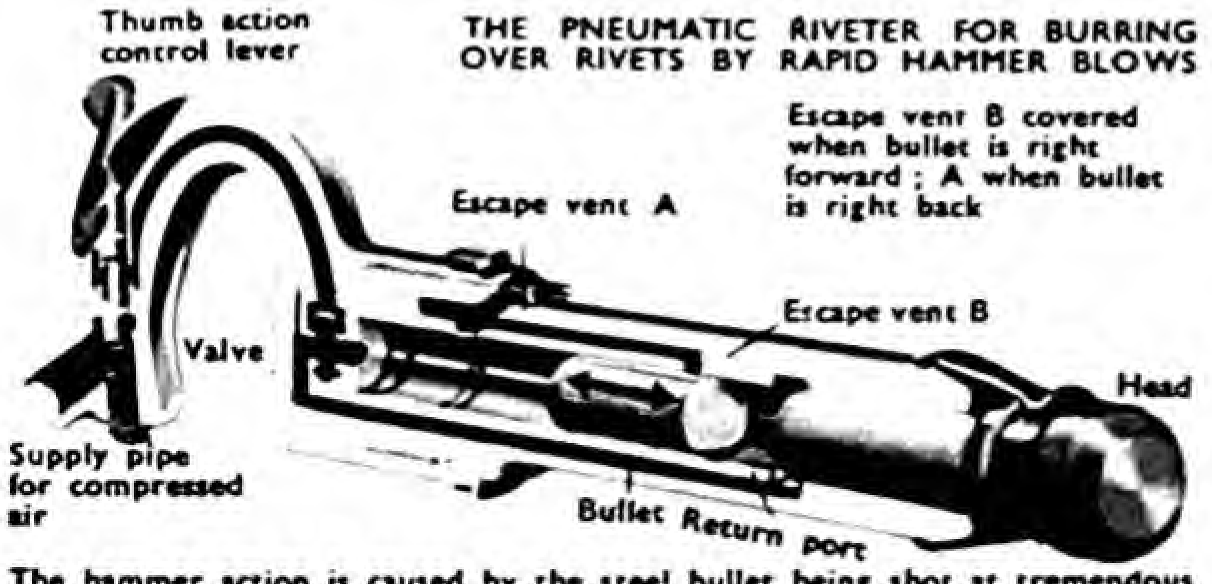
Rotary pumps, used in oil pipe lines, act like a ship's propeller.



Diaphragm pump's piston is flexible and moves without sliding up and down the cylinder.

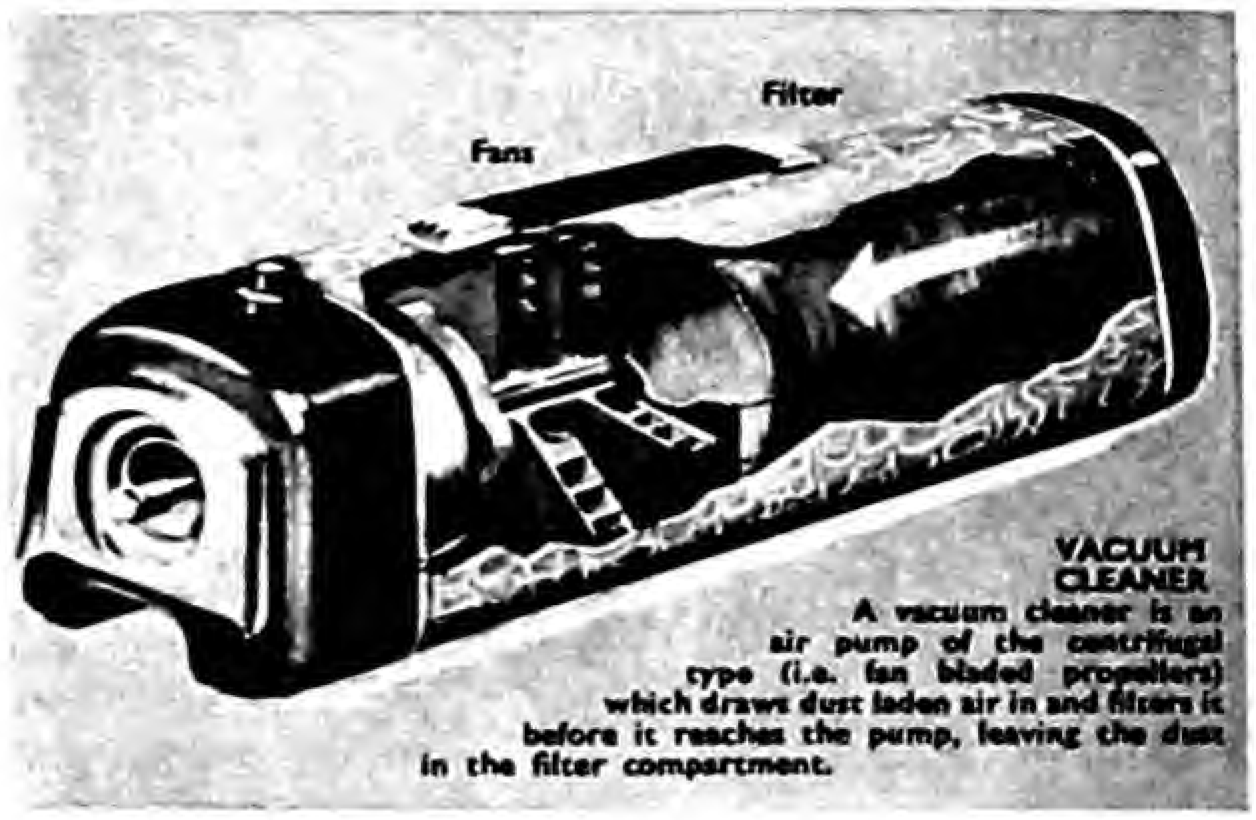


The air dome of the force pump makes the water spurt out in a continuous stream. Without it the water only gushes out at each stroke.

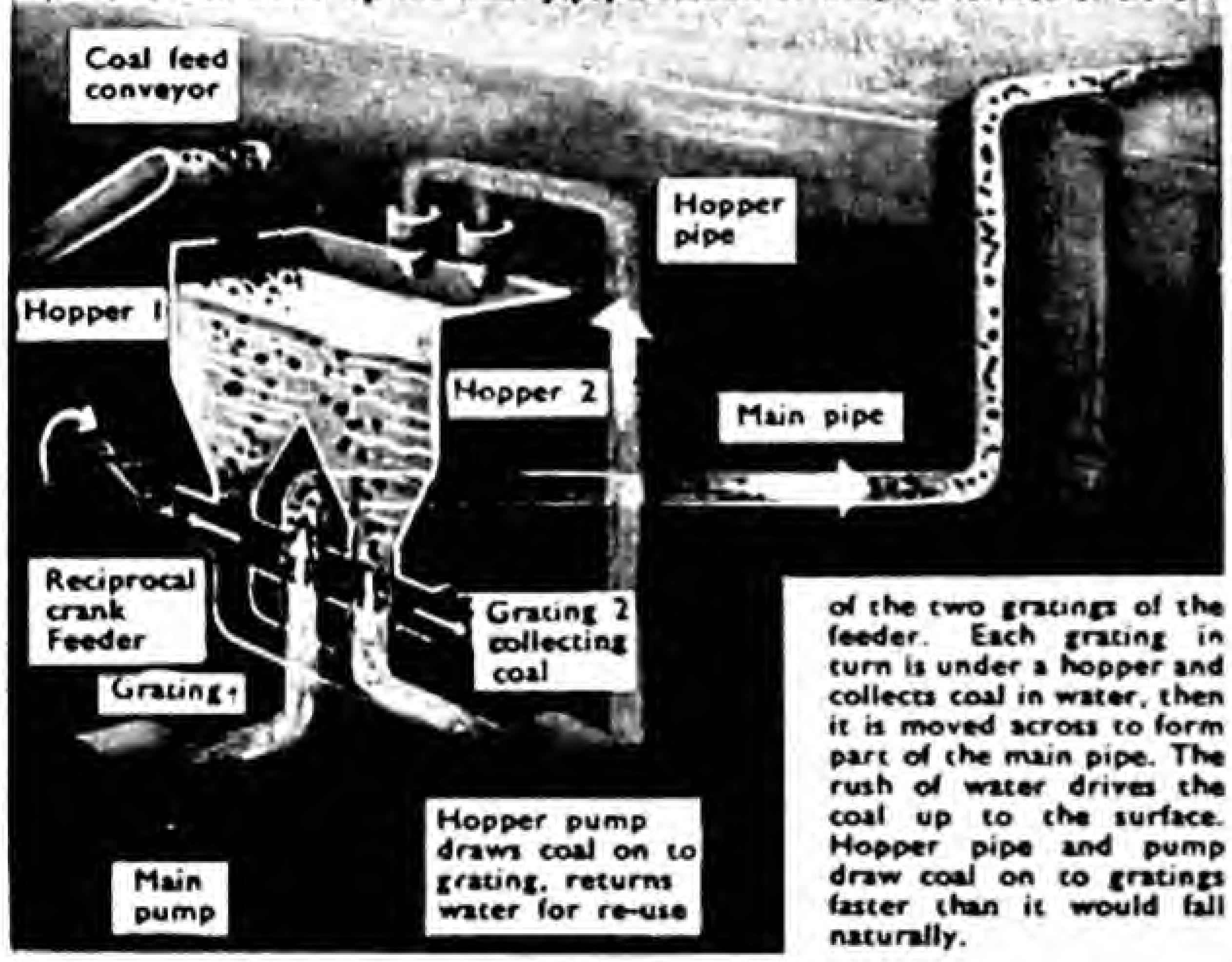


THE PNEUMATIC RIVETER FOR BURRING OVER RIVETS BY RAPID HAMMER BLOWS

The hammer action is caused by the steel bullet being shot at tremendous speed down the cylinder to strike the head. Pushing down the control lever lets compressed air through the valve chamber where it has two routes : (1) valve leaf back—straight into cylinder behind bullet, which it drives forward, drawing after it valve leaf; (2) valve leaf now forward—air goes behind cylinder along passage to return port, blows up in front of bullet and drives it back. Alternative escape routes for exhaust are at A and B.

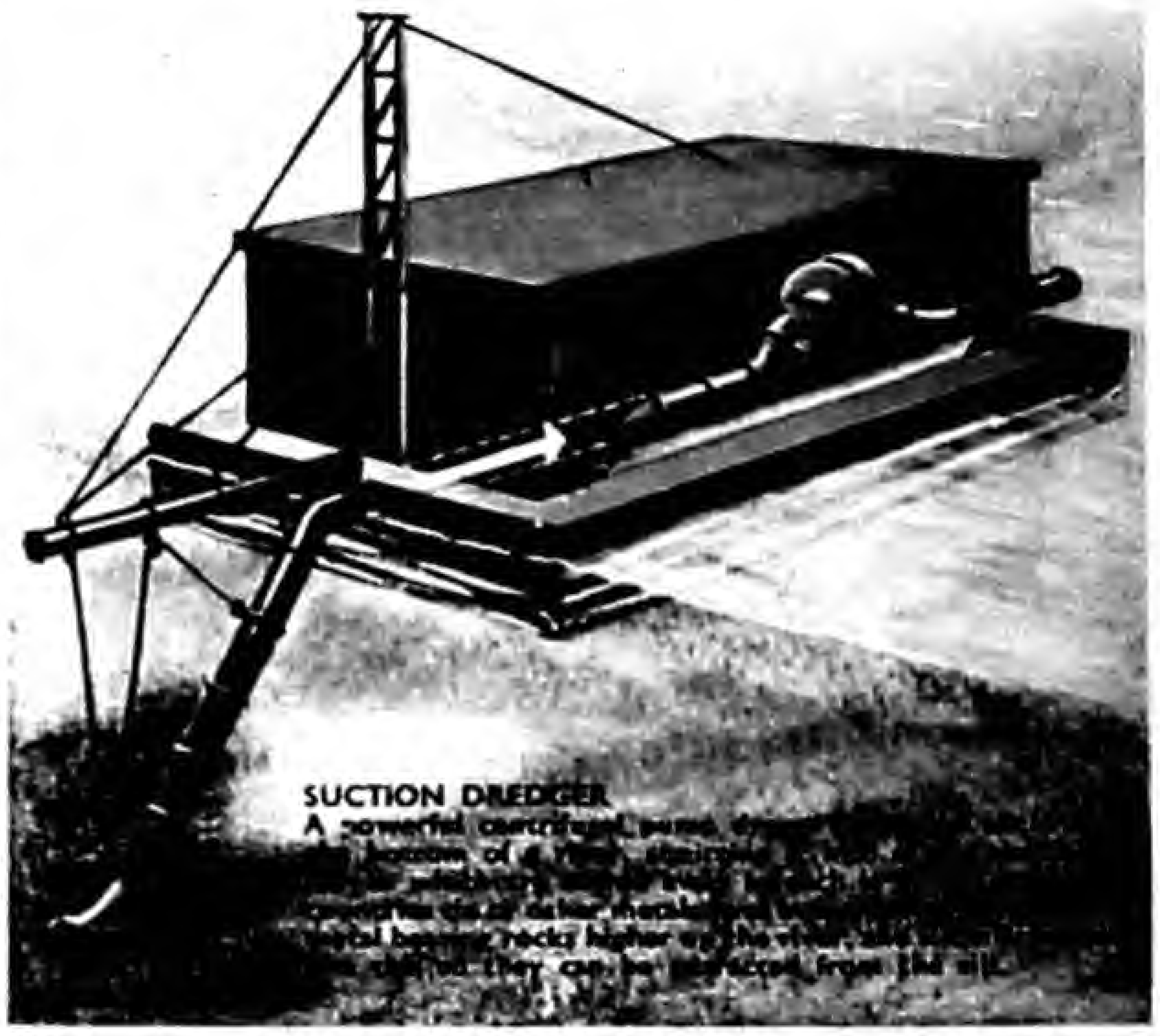


VACUUM CLEANER
A vacuum cleaner is an air pump of the centrifugal type (i.e. fan bladed propellers) which draws dust laden air in and filters it before it reaches the pump, leaving the dust in the filter compartment.



PUMPING COAL IN A COLUMN OF WATER FROM PIT BOTTOM TO SURFACE

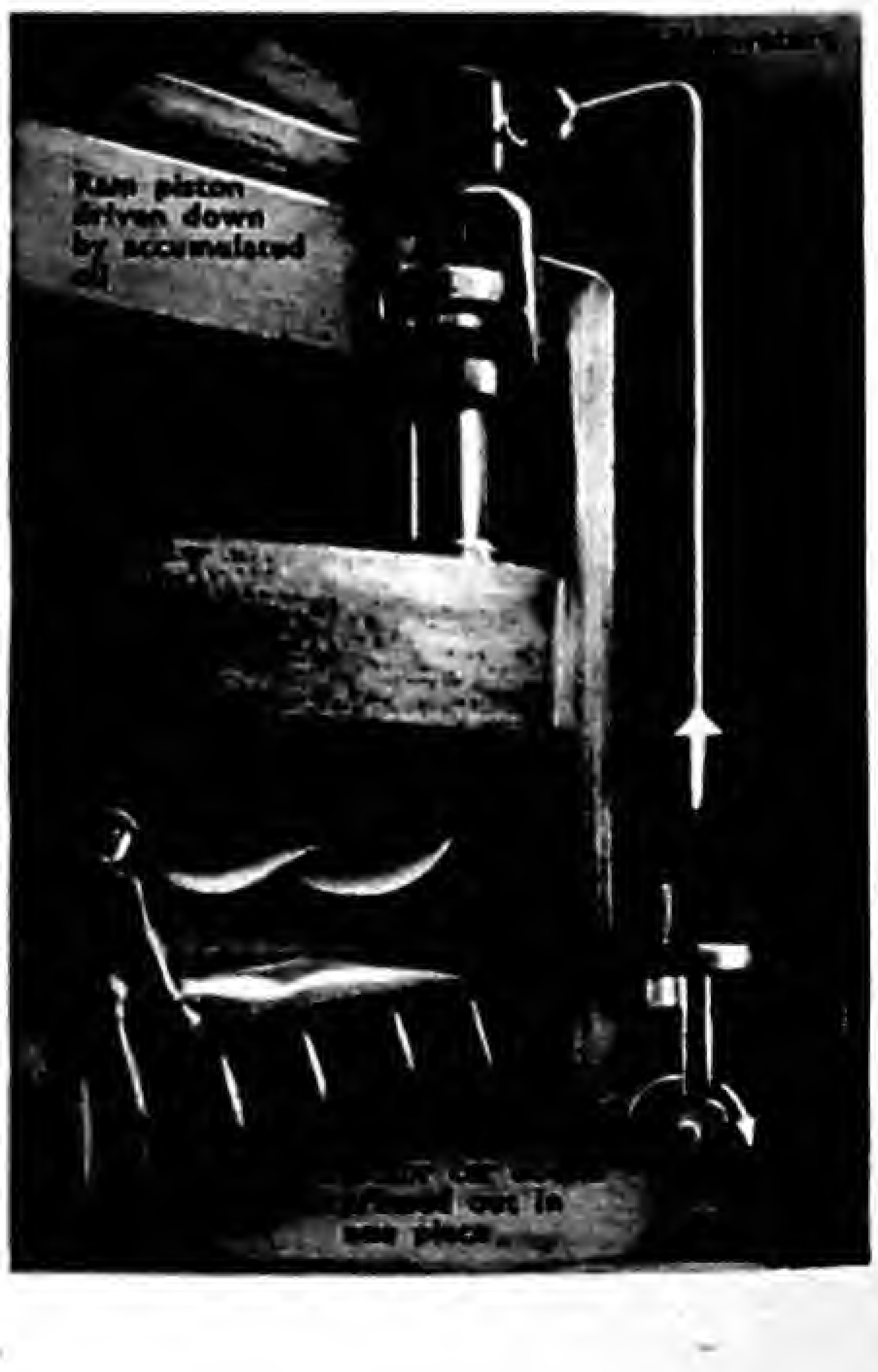
Solids can be transported hydraulically through pipes suspended in liquid. A pump drives water up the main pipe, a section of which is formed of either of the two gratings of the feeder. Each grating in turn is under a hopper and collects coal in water, then it is moved across to form part of the main pipe. The rush of water drives the coal up to the surface. Hopper pipe and pump draw coal on to gratings faster than it would fall naturally.



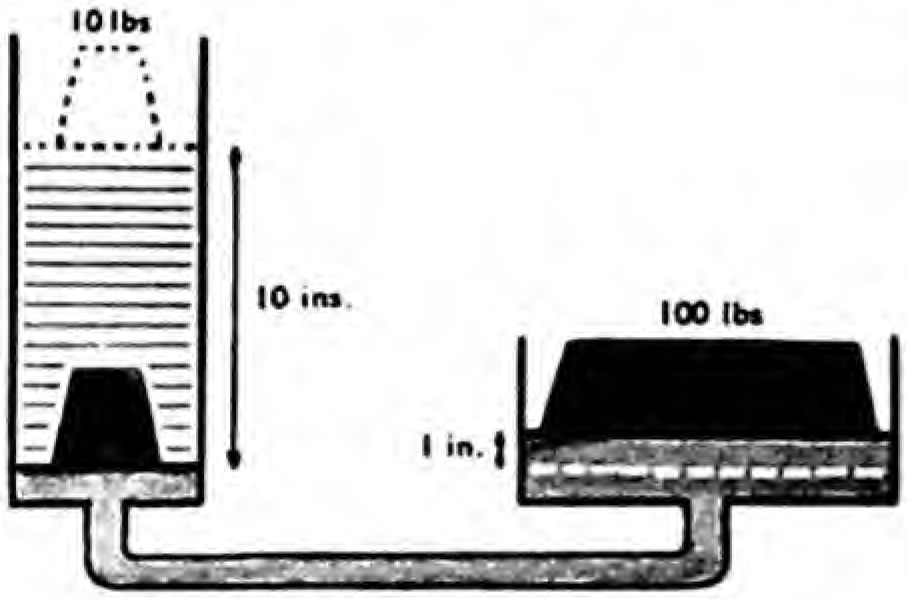
SUCTION DREDGER

HYDRAULICS

Right: A giant hydraulic press stamping steel.



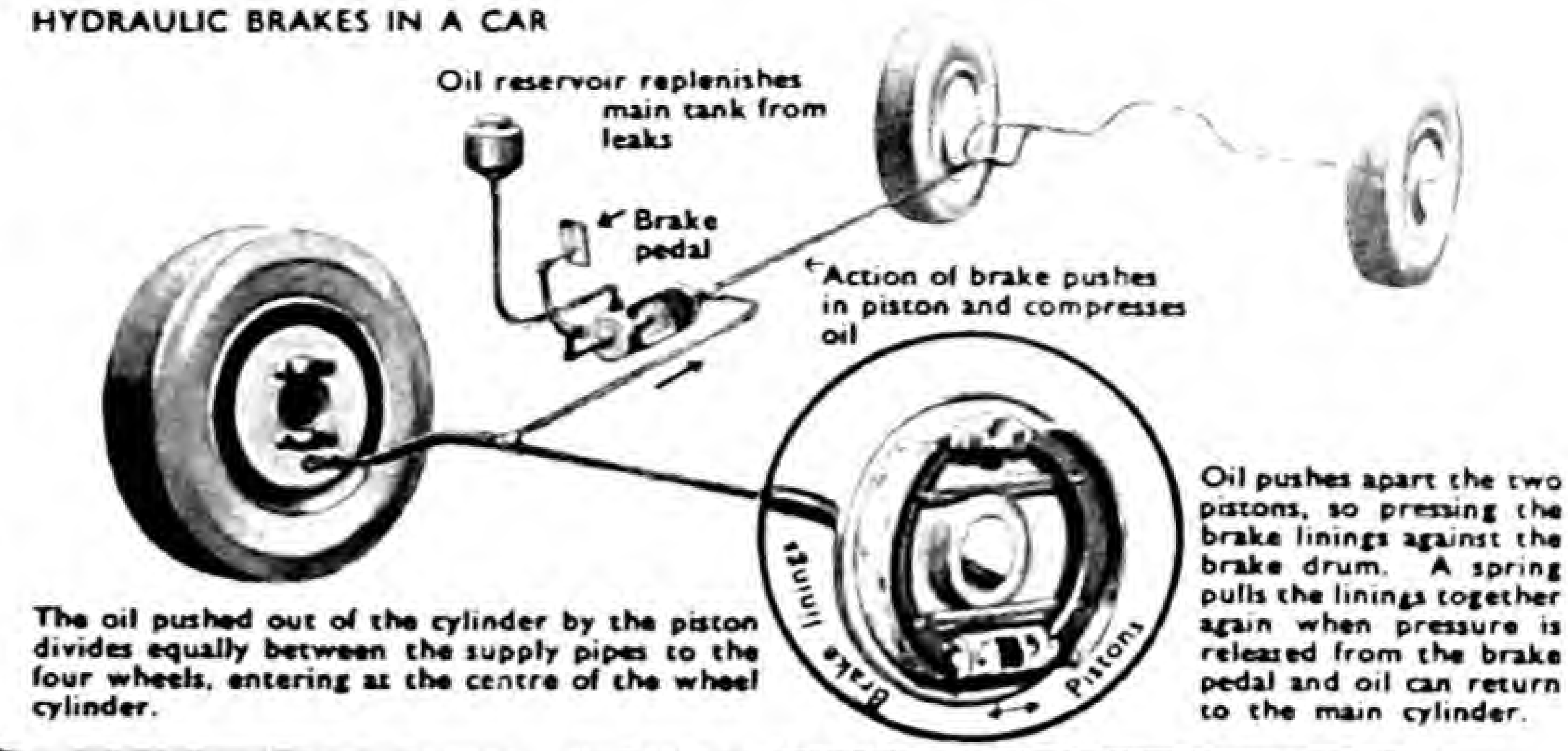
In its simplest form, as a diagram like the one below, hydraulic power is known to most people. It shows a 10 lbs. force moving a 10-square inch cylinder down 10 inches and hydraulically raising a 100 square inch cylinder 1 inch with a 100 lbs. weight on it. The practical use of hydraulic power involves some extra features when convenient preparation of the initial force, and its storage until needed, and its direction to one of the several possible jobs are needed.

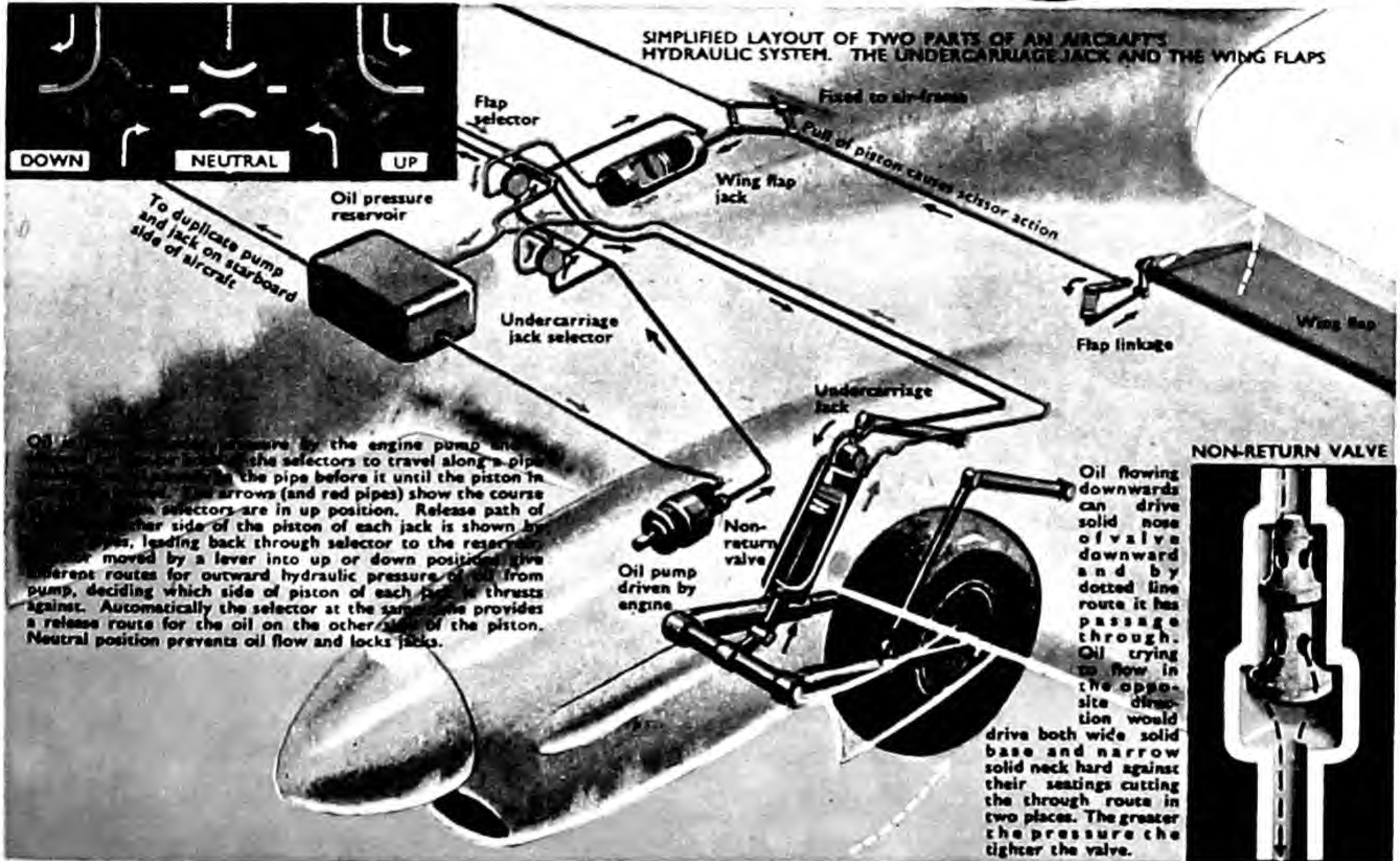


First it is easier to use a pump to force the hydraulic fluid under pressure into a strengthened tank for

a period, than to find a direct source of mechanical power that would be as strong as the total force built up by the pump. The tank acts as a reservoir of force, so it can be drawn upon at any time and to any amount up to its total.

To ensure that a hydraulically operated movement will "stay put" without the initial





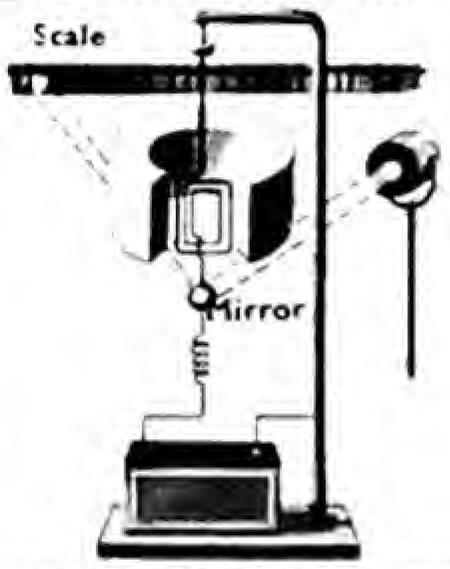
Pelton Wheel. Hydraulic pressure of water in a narrow pipe can either be caused by a pump or by a great weight of water in a dam. In either case the jet will drive a wheel with buckets on it at great speed. Such Pelton wheels are used to turn electric generators in hydro-electric schemes.

force being kept on all the time, non-return valves are used and pistons are pushed from either end of a cylinder to allow the movement to be reversed. Selector "gates" allow a separate route for hydraulic fluid to each end of every operating cylinder.

Hydraulic transmission systems consist of two plates each with a set of vanes mounted on it, one plate on a driving spindle, and one plate on the driven spindle. Both are immersed in an oil filled chamber. At high revolutions the driving plate by centrifugal force throws oil onto the vanes of the other plate so driving them around hydraulically.

RESEARCH INSTRUMENTS

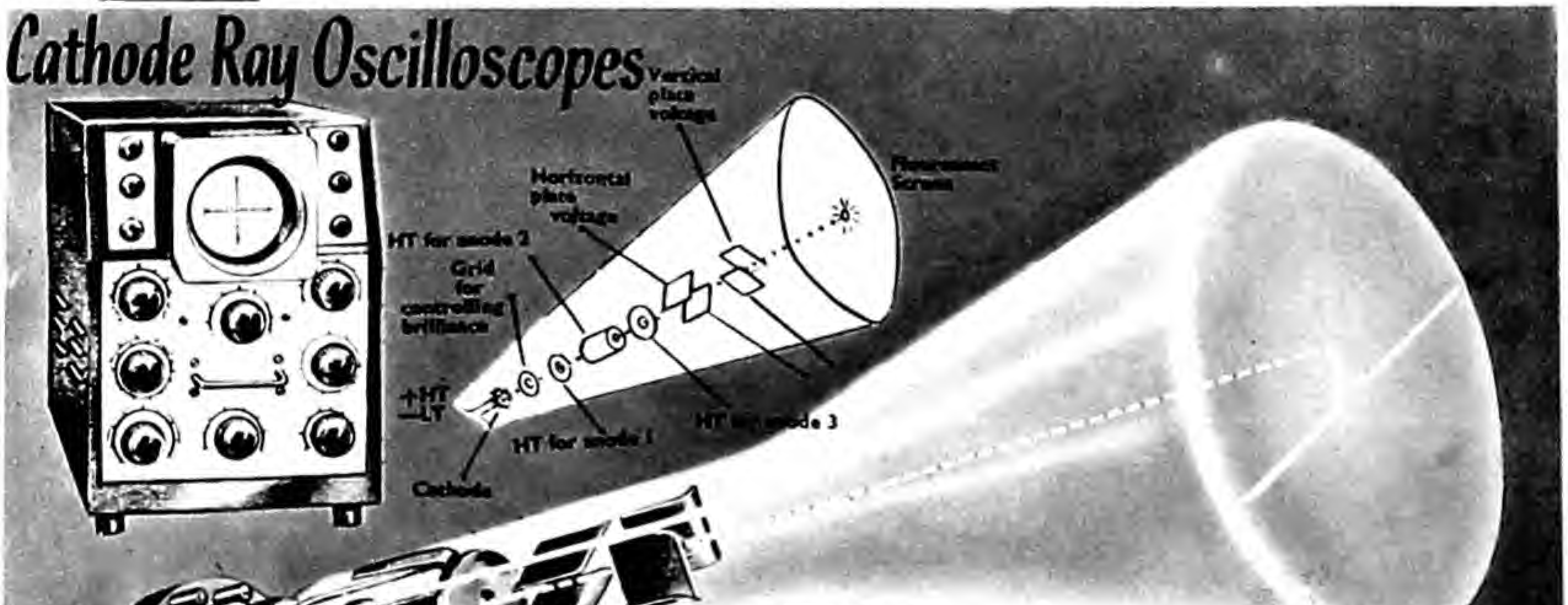
The Mirror Galvanometer



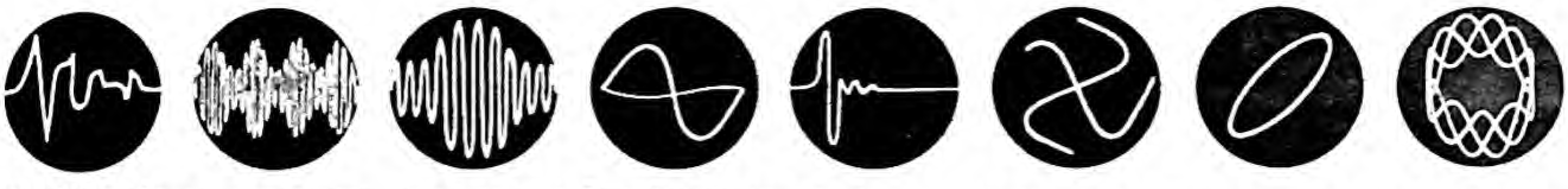
A very minute electric current flowing through a loop of wire hung between the poles of a magnet will turn the loop perhaps a fraction of a degree—not enough to see. The little mirror turns with the loop and the beam of light it reflects moves across the giant scale on the wall. It can with amplification measure 1/1,000,000th amp.

The research instruments mentioned here have mostly been developed as a result of discoveries in the field of physics. But they have enabled workers in many other fields of science to record and measure in a way not previously possible. They have helped to make possible the great advances of scientific research during this century.

All sorts of instruments and apparatus are used in research work. Often they are specially invented for a single experiment. Much research equipment is very simple—at one time it was said that no atomic physicist needed more apparatus than a biscuit tin and a supply of photographic plates! Rutherford's fundamental studies of alpha rays show how great discoveries can be made with only the simplest of apparatus (*see pages* 193-201). And it is still true in these days of more elaborate apparatus that careful observation is the chief means by which scientific discoveries are made. But the natural limits to man's senses for long made observation impossible in certain fields. Some things are too small to be visible, since they cannot disturb light waves (*see pages* 11, 12). Some movements are too fast to be seen. Electric currents may be too small for ordinary methods of measurement. It is impossible to see directly the interior structure of opaque materials. Atomic particles are far below the limits of direct observation. To control them in bombardment experiments requires the use of special electrical methods. In all these fields of research advances have had to wait upon the development of suitable instruments.



Where a process lasts perhaps only one millionth of a second but is repeated over and over again, the electron beam of a cathode ray tube can trace out a graph of the changes happening during the process. An example of what can be studied is the surges of electricity in a piece of vibrating quartz crystal held between electrified plates. In the CRT a timebase signal is placed across the horizontal plates. By voltage changes this attracts the electron beam across the tube, each journey taking perhaps a 20 millionth of a second. This is timed so that when voltages tapped from the process under test (the incoming signal from the quartz crystal) are passed to the vertical plates, the electron beam is raised or lowered during each journey across the screen. The variations in the signal studied then appear just like a graph, for the glow caused by the oscillating beam of electrons striking the fluorescent screen as the beam traces across the screen time after time seems to the observer like one picture. Of course if the investigator modifies the process under test so it undergoes *gradual* change, that will make the trace itself change gradually like a moving picture. (Indeed an elaboration of this is the basis whereby a picture is transmitted—televised.)



Visualising the pressure variation in the hydraulic system of a bomber.

An ordinary A.M. radio signal—a radio frequency varying in amplitude of audio (hearing) frequencies.

Time base adjusted to show single beat of audio modulation of radio frequency.

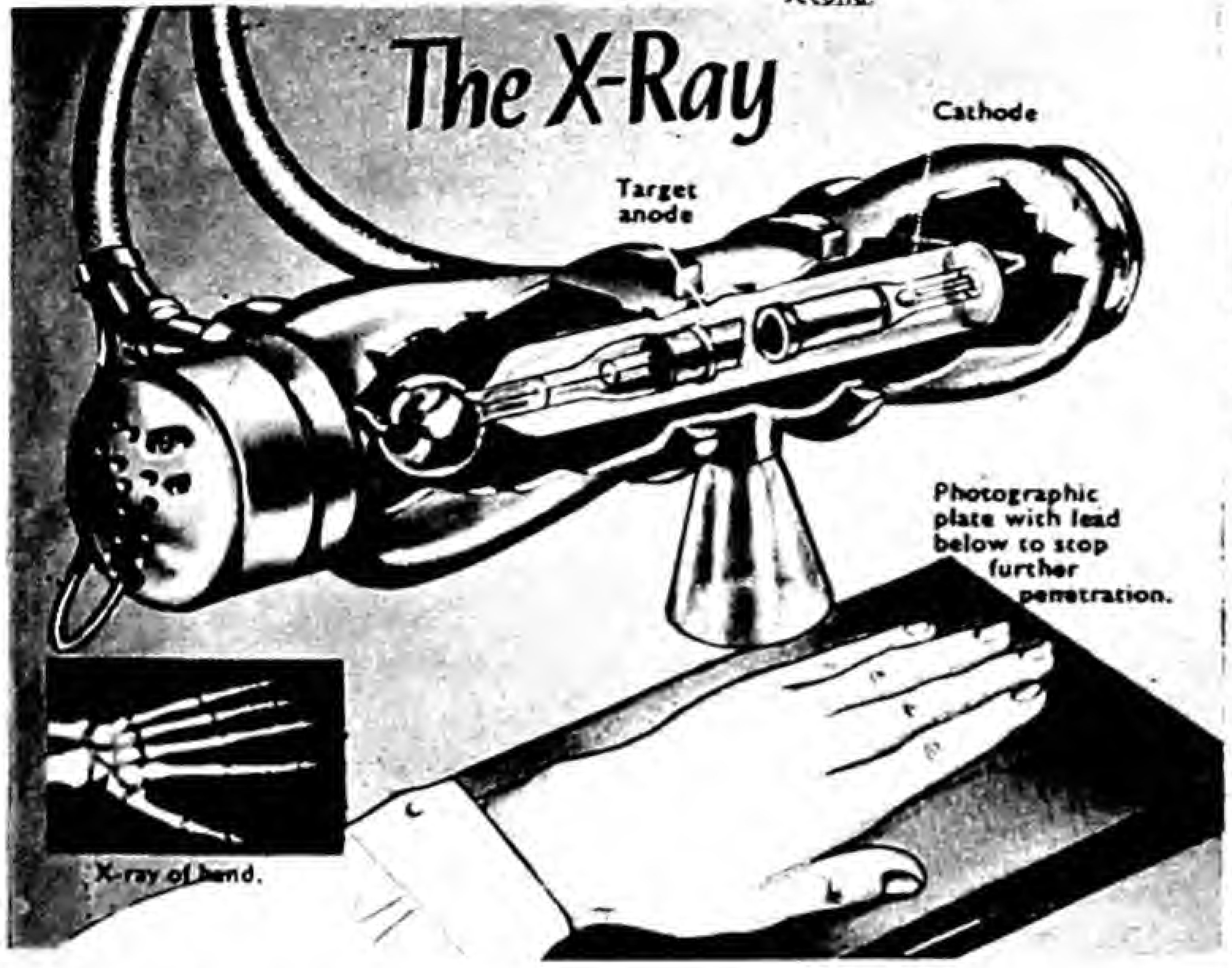
Time base lengthened again to show a single R.F. wave form which lasts only one nine hundred thousandth of a second.

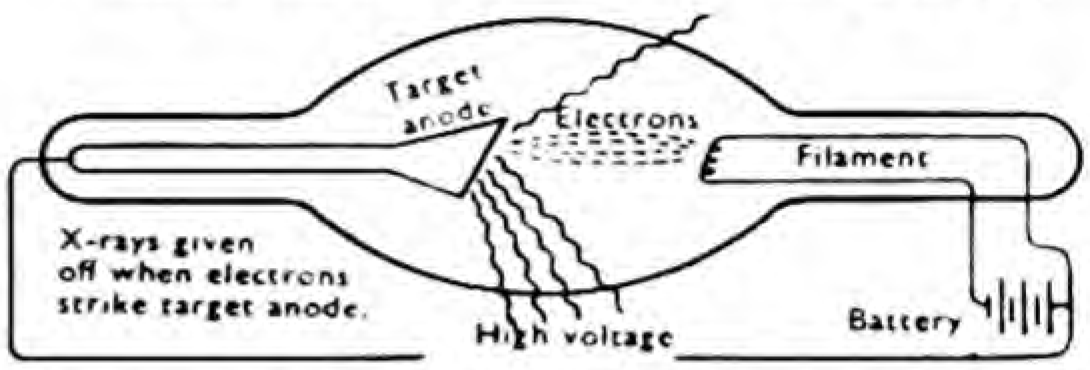
What happens in a T.V. oscilator circuit in two millionths of a second.

Visible mathematics. If these two waves of the same frequency but 30 out of phase (here on separate beams) are fed into the cathode ray tube horizontal and vertical plates of one beam it presents a graph of the result.

Very complicated graphs can be pictured in this way. This is an oscillogram of one frequency 2 2,3 times that of the other

The X-Ray



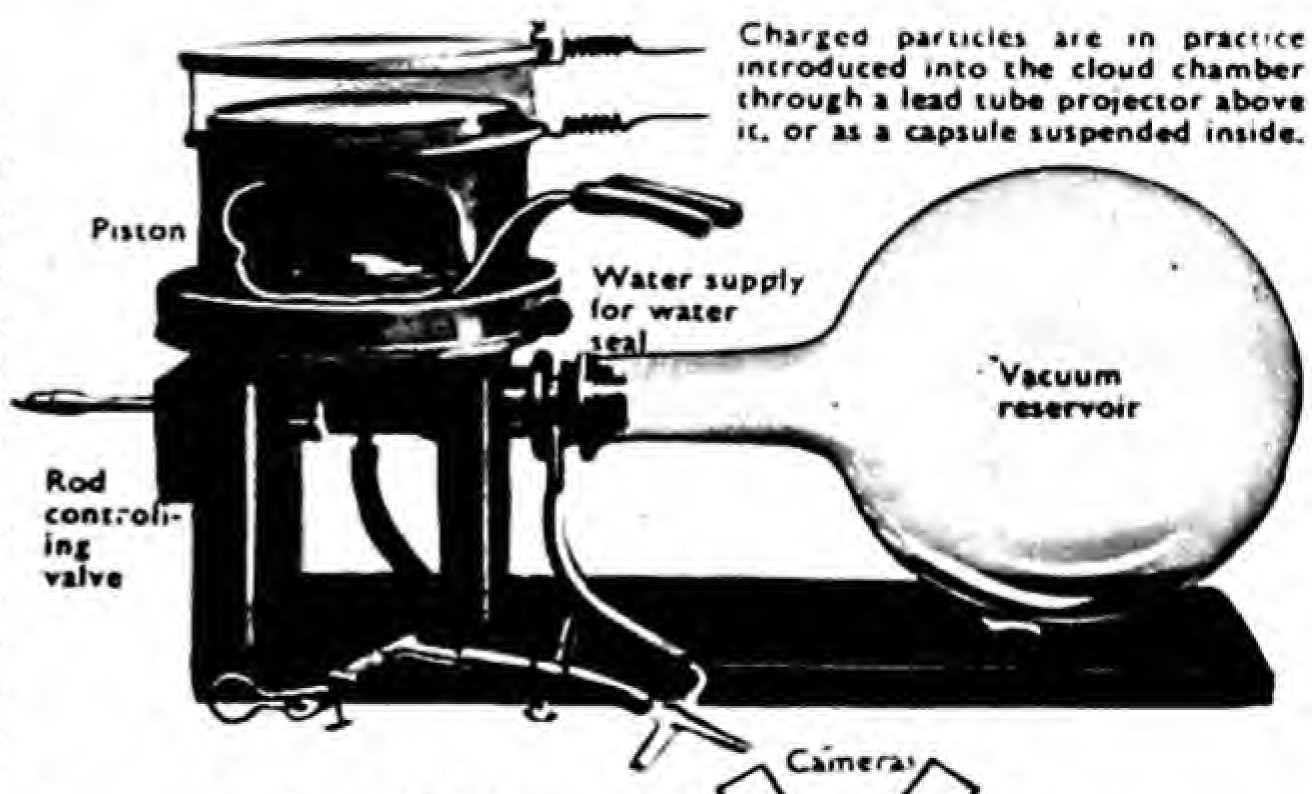


X-rays are electro-magnetic radiations like light but of a very much higher frequency. Unlike light they are hardly reflected at all at surfaces of opaque things, nor are they bent (or refracted) in going from one material to another. This means they will penetrate where light will not, more strongly through some materials than through others, and casting shadows where they have not penetrated so easily. X-rays affect photographic plates, though radiographs are not strictly speaking photographs (which are caused by *reflected light*) but shadowgraphs. X-rays will fluoresce on a screen of platinum barium chloride.

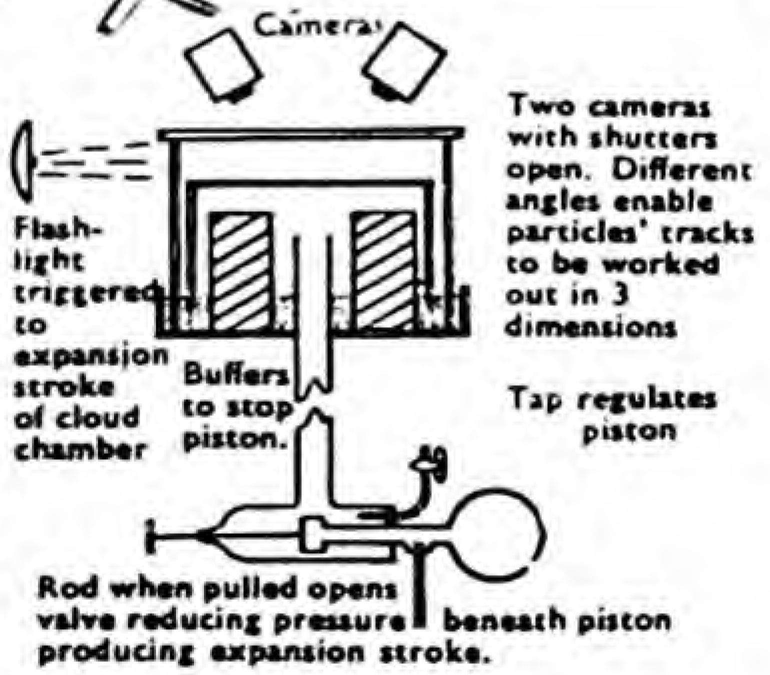
Photographic Plates and the Cloud Chamber

Three separate emissions of alpha particles, as thorium disintegrates in stages in a photographic emulsion.

Strangely enough the most revolutionary discoveries which led to the present atomic age of physics, were made with the ordinary photographic plate. Early experimenters with the natural radio-active substances noticed that a box of photographic plates, though not exposed at all to light, had faint patches on the plates after being left near pitchblende, as if light had leaked into the box. These were the result of passage made by atomic particles released from the radio-active substances. Later refinements of the basic idea of atomic structure were deduced from the study of radio active rays causing sparkles (scintillating) when they strike a screen coated with zinc sulphide (like a television screen). Then the actual path of the radiations was recorded by their being released from within an emulsion of a special radioactive photographic plate.



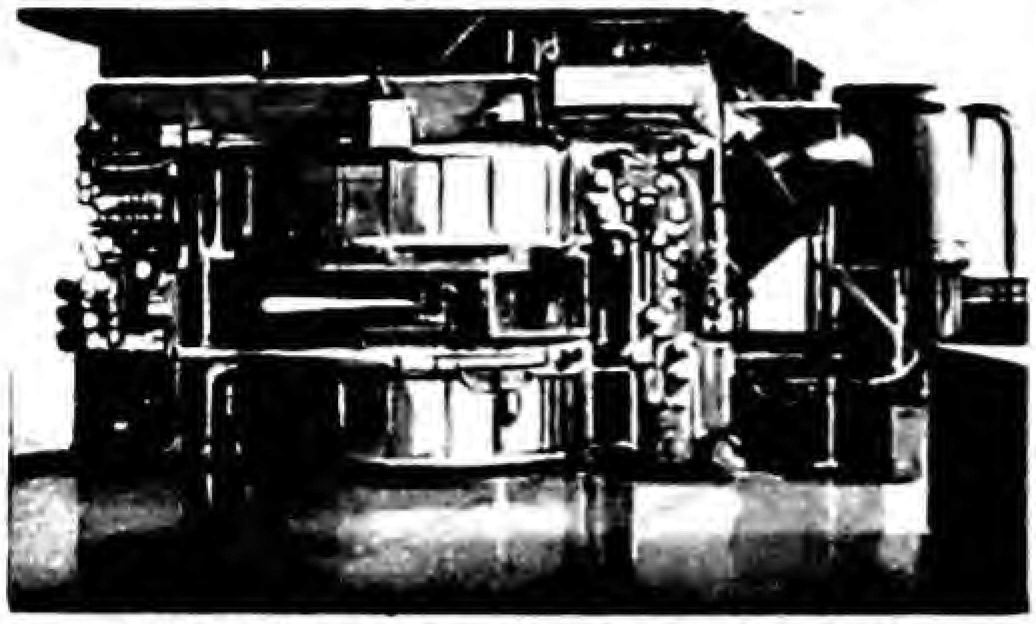
Charged particles are in practice introduced into the cloud chamber through a lead tube projector above it, or as a capsule suspended inside.



THE CLOUD CHAMBER

The course of a jet aircraft can be seen from its vapour trail even when the plane itself is flying too high to be seen. The cloud chamber is a device for letting charged atom particles too small to see reveal their paths as a vapour trail in the cloud chamber, which contains air and water vapour at less than atmospheric pressure. When the sliding piston is pulled down very quickly, expanding the thin air and lessening its pressure still further the water vapour is cooled and becomes very ready to turn into water droplets if something is supplied for it to settle on. The passing of a charged particle through the thin air (in which the molecules of gas are spread out enough to prevent too many collisions) forms a whole string of ions of gas from the gas atoms along its path into which it has bumped knocking off their electrons (see *Ionization page* 130). Round these ions the water vapour forms as visible droplets, these miniature vapour trails brightly lighted, are photographed through the glass top of the cloud chamber. To put the cloud chamber back to normal for another photograph the suction under the piston is released, and from the heat of this compression the water droplets in the air turn back to vapour.

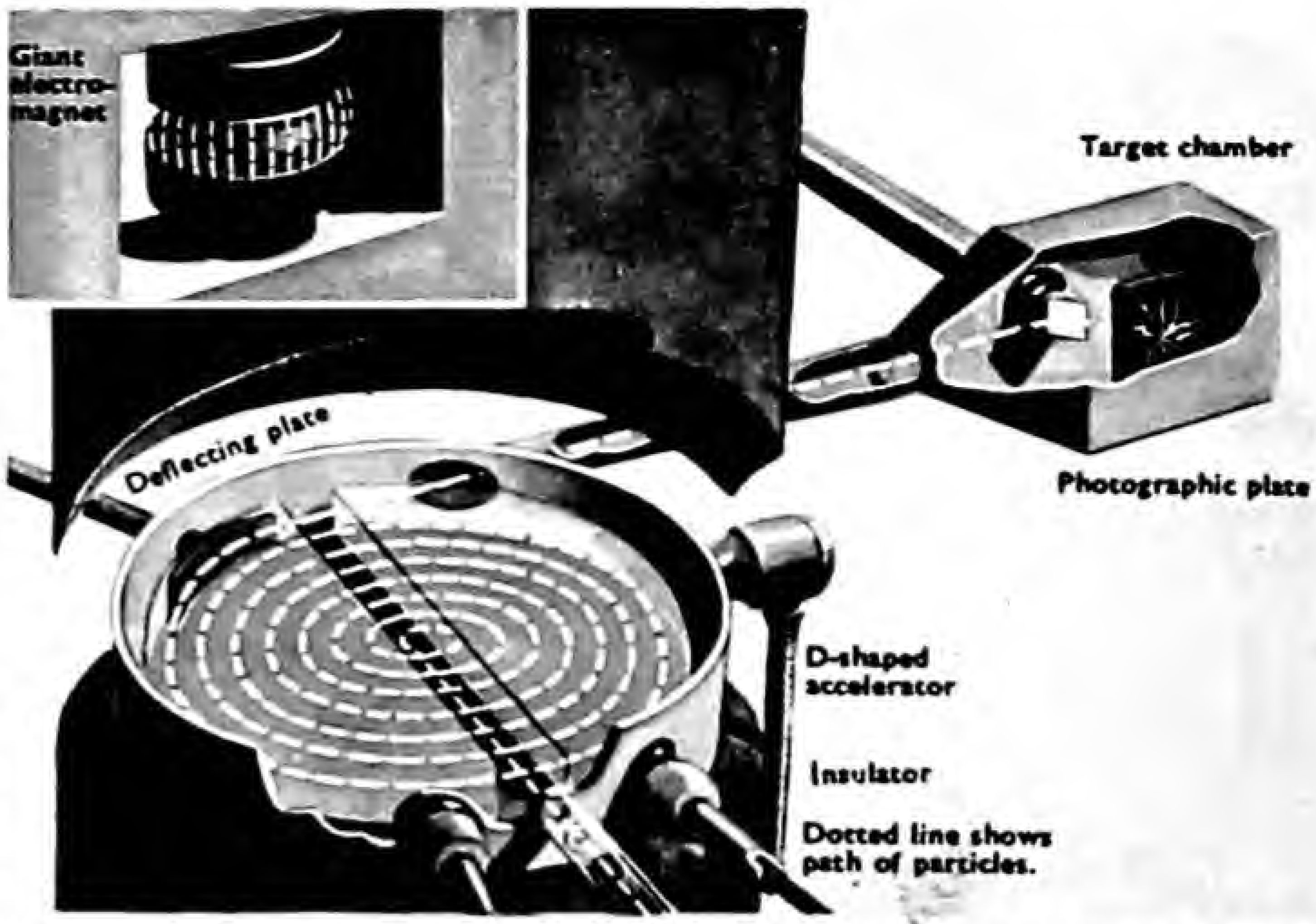
The Cyclotron



CYCLOTRON WITH PARTICLE BEAM EMERGING

Atomic particles have to be travelling at speeds of many thousands of miles per second if they are to be of any use in bombarding other atoms. And without bombardment and the resulting effects (which may include the sudden disrupting of the atom) the existence of any internal structure to atoms could not have been discovered.

One of the most valuable of the atomic physicists' research instruments, the cyclotron, is a good deal easier to use than the earlier accelerators that required very high voltages for their successful operation. The cyclotron accelerates charged particles by means of suitably applied relatively small voltages, = 50,000 volts as against up to 2 million volts in other types. The particles (usually protons or deuterons, not electrons) are projected into the centre of two D-shaped boxes in

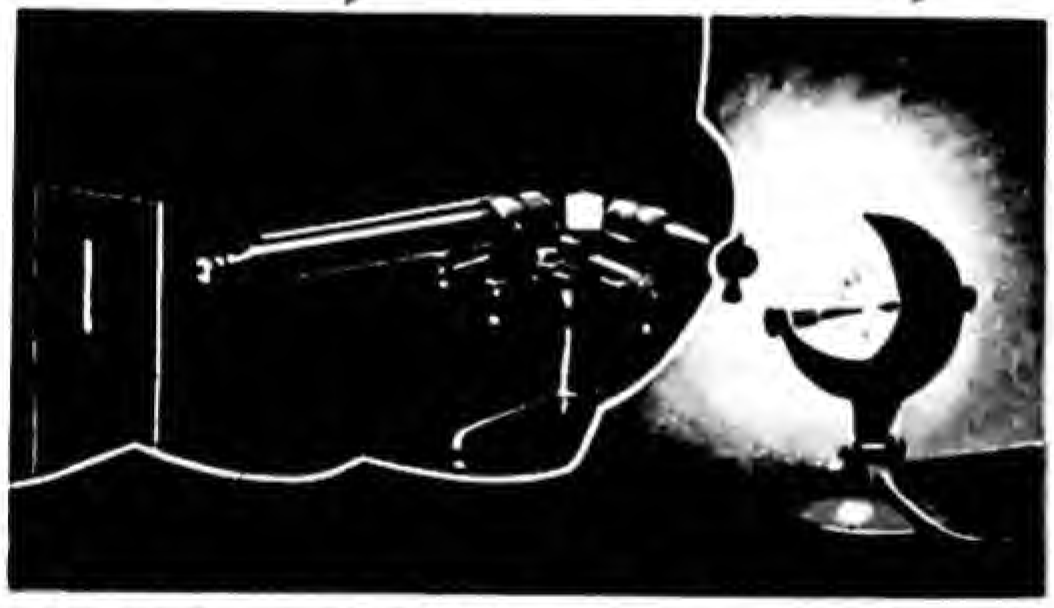


an evacuated container. The whole of this rests between the poles of a large electro-magnet (the poles may be 20 feet wide), and each D-box is wired to an alternating voltage supply (that is current flows first one way and then the other).

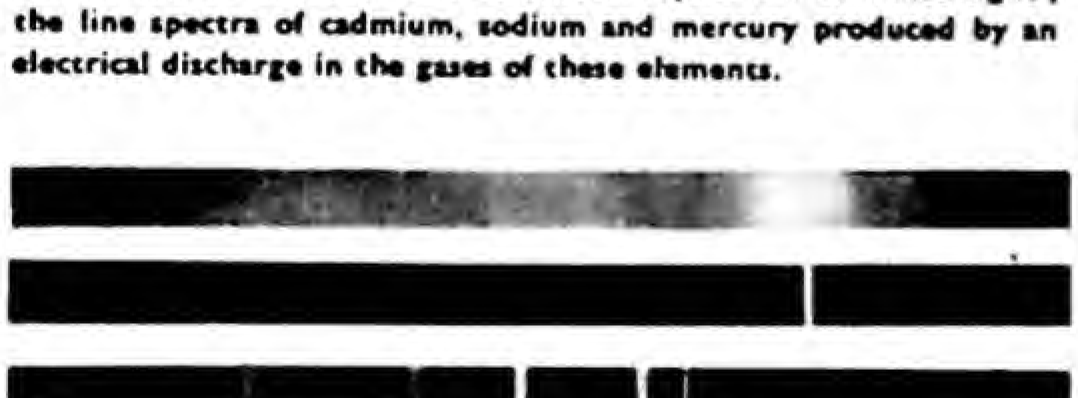
The magnetic field of the magnet causes the positively charged particles to move in circular paths. When a D piece becomes negatively charged the positive particles in the gap move towards it, and are accelerated. Still moving in a curved path they travel through the D-box. As they are about to leave this D piece its voltage is reversed, and the other D becomes negatively charged, so that the particles are accelerated again. The frequency of this voltage change must depend on the time taken by a particle to travel the half circle. Fortunately this time is the same no matter what may be the radius of the curve which the particle is following. Thus the same AC period accelerates all the moving particles in the cyclotron. Now the faster any particle moves the less is the effect on it of the magnetic field. Thus after each complete passage a particle follows a path of greater radius until after several hundred circuits the perimeter of the D is reached. A negatively charged deflector plate then sends the beam of particles out of the instrument through a thin aluminium " window ".

One difficulty that physicists have met in using the cyclotron is that as the speed of the moving particle approaches the speed of light (186,000 miles per second) it cannot easily be accelerated further, since it begins to show Einstein's relativity effect. When this occurs the mass (or weight) of the particle begins to increase as its speed increases. As a result it gets out of step with the alternating voltages of the cyclotron. In the more recently developed synchrotron this difficulty has been got round.

The Spectroscope



White light seen through a glass prism is divided into the colours of the spectrum which make it up. This is called a continuous spectrum. When substances such as sodium are vaporized in a flame the light from the coloured flame is divided by a prism into separate bands of colour. Which colours appear in a spectrum, and the width of the bands, depends on the particular substance. The presence of different elements in the light of distant stars is detected by this means. The spectroscope is very useful for identifying unknown substances by this means, for each element has its own spectrum. Below, top to bottom: the continuous spectrum of white light; the line spectra of cadmium, sodium and mercury produced by an electrical discharge in the gases of these elements.



High Speed Photography

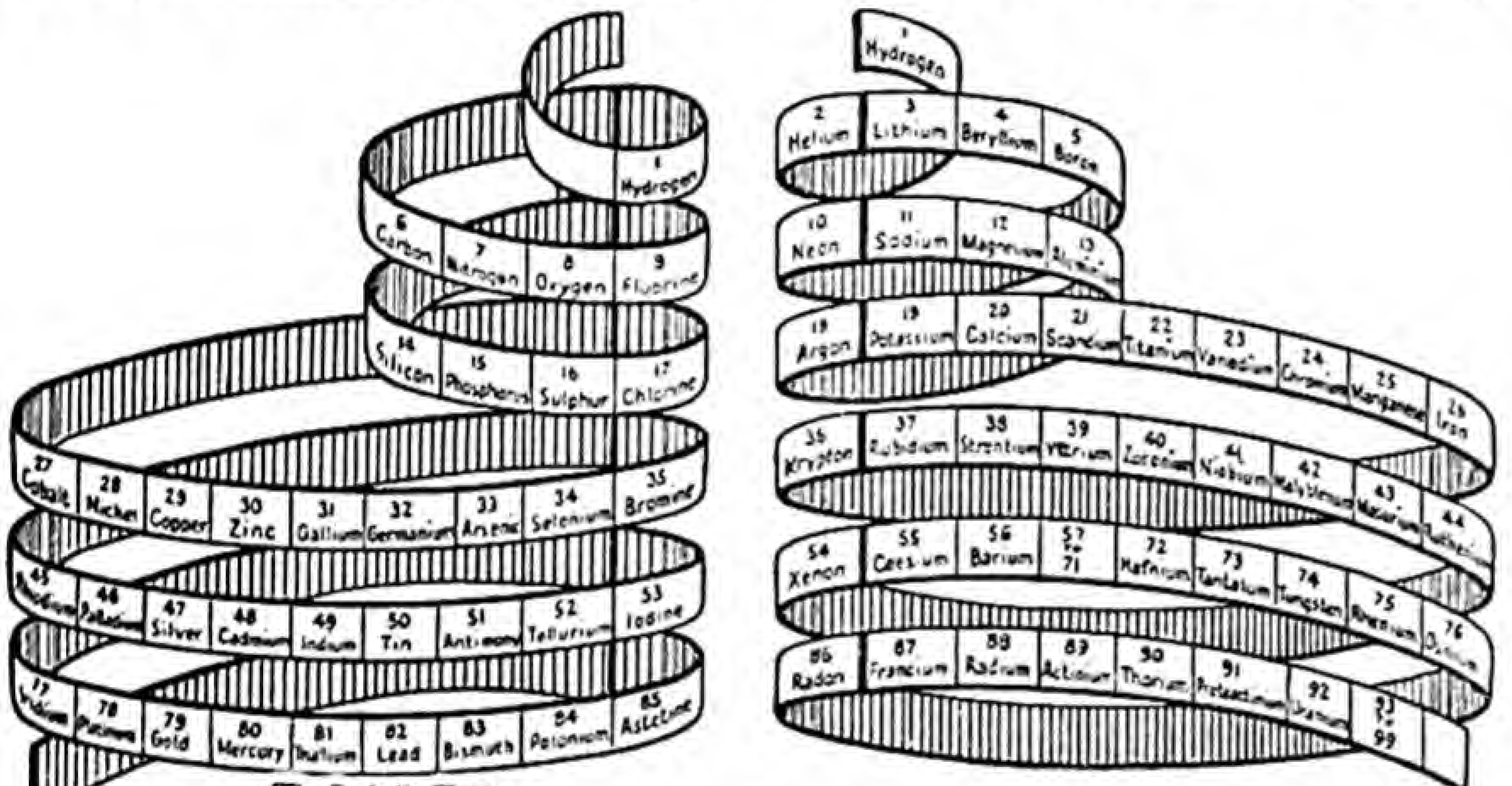
The speed of the shutter of a camera is governed by the difficulty of moving the parts of the shutter out and back by springs at really high speeds. To catch such subjects as the moment of impact of a bullet needs another method. It is to leave everything in darkness, the shutter open, and to trigger off a pulse of electricity (like those used in television) by the shadow of the passing bullet affecting a photo-electric cell.

The pulse, a few hundred thousandths of a second in duration, lights a flashlamp for just so long, and the exposure of the photographic plate is so brief as to be able to catch something happening immensely quickly. Some examples of high speed photography are shown below. Left to right: A lump of sugar dropping into a cup of tea; a balloon being burst by a dart; the explosion of a thin wire by an electric discharge (the unfired wire is at the top).

WHAT IS THE WORLD MADE OF?

Some Clues from Electricity

In the section on chemistry you have learned that the materials of the earth are formed by the combination in an enormous variety of ways of a limited number of substances known as elements. These occur in the stars as well, as can be discovered from a study of the spectrum obtained from a star's light. When the elements are set out in the order of their atomic weights they show a considerable, though not perfect, regularity in their properties that is represented in the diagram shown here. In the earlier turns of the spiral, disregarding hydrogen, which is the lightest element and a rather special case, every eighth element in the grouping shows strong family likeness to the element eight places (or one complete turn) below it on the ribbon (like the octaves on a piano). Lithium, sodium, and potassium are all similarly behaving metals with valency 1. Helium, neon, and argon are all unreactive rare gases of valency 0. Beyond argon the rhythm continues, but with longer periods of 18; the lithium series being continued by rubidium and caesium; the helium series by krypton, xenon and radon. Why this should happen puzzled chemists a lot. Mendeléef demonstrated this orderliness in nature in 1869, but it took forty years (till 1911) to find the explanation!



The Periodic Table

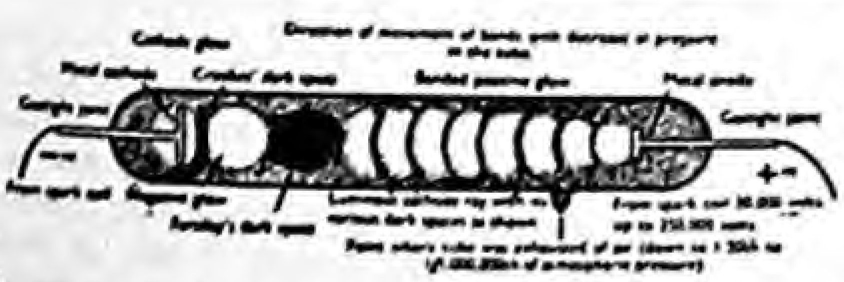


Fig. 1. *Cathode ray tube with banded glows (geissler effect)* when pressure is about 1/1,500th atmospheric. Under these conditions no X rays are produced from the anode.

In 1895 Roentgen discovered the production of X rays when high-voltage electricity was passed through a near vacuum, in what has come to be called a cathode ray tube. These X rays have proved to be like light, only of much shorter wavelength, from which fact results their great penetrating power. Crookes and J. J. Thomson studied the glow, or ray which comes from the negative electrode, or cathode, and by its effect on the metal anode (positive electrode) causes the X rays to be given out. In 1897 J. J. Thomson showed that the beam of cathode rays was bent when it passed through a magnetic field. This suggested that cathode rays are made up of particles of negative electricity carrying the current across the near vacuum, especially as they are also deflected by an electric field (*see* figs. 1A–D).

From his measurement of the exact amount of this bending (deflection) in fields of known strength Thomson could calculate both the speed (v) of these particles and the ratio of their charge to their mass or weight $\frac{e}{m}$. The value of v was found to be $\frac{1}{10}$th the speed of light, so cathode rays could not be light rays. In 1899 Thomson used the cloud-chamber method of C. T. R. Wilson to find the value of the electric charge (e) on the particles. Now the value of $\frac{e}{m}$ is found to be independent of what gas is in the tube, or what metal is used for the electrodes, whilst e is found to be equal in value to the charge on monovalent ions (i.e. charged molecules of valency 1) in liquids. Calculation shows the value of m is very small, being 1/1,837th part of the weight of the hydrogen atom. From these results Thomson concluded that the cathode ray must consist of a special sort of matter that he called free electrons, and that positively charged ions are formed when molecules lose some of these electrons and negatively charged ones are formed when molecules gain electrons. This conclusion means that electrons are essential parts of all atoms, which can lose them or gain them according to circumstances. Here then was a common basis for all matter.

In 1899 J. J. Thomson wrote: "In the normal atom this assemblage of corpuscles (= modern electrons) forms a system that is electrically neutral. Though the individual corpuscles behave like negative ions, yet when they are assembled in a neutral atom the negative effect is balanced by something, which causes the space through which the corpuscles are spread, to act as if it had a charge of positive electricity equal in amount to the sum of the negative charges on the corpuscles."

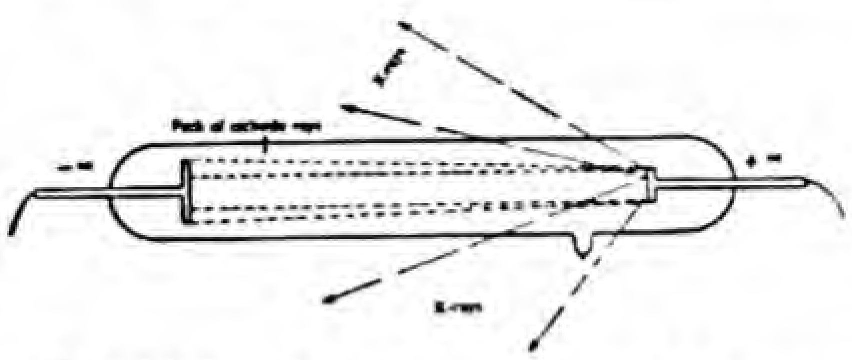


Fig. 1(a). At pressures as low as 1/8,000th atmosphere Crookes dark space extends from cathode to anode—i.e. the cathode rays, though shown here, diagrammatically are no longer actually visible. Where they fall on the glass walls of the tube these may fluoresce with a greenish light. X rays are emitted by metal objects (e.g. the anode) on which these cathode rays fall under these conditions of low pressure.

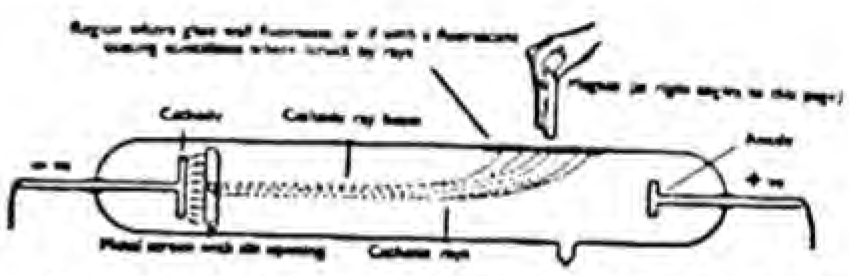


Fig. 1(b). *A magnetic field bends cathode ray. Note:* The magnet is *NOT* attracting magnetic particles. Actually that part of its field which comes within the tube causes electrons coming within its influence to be deflected. The field is at right angles to this page.

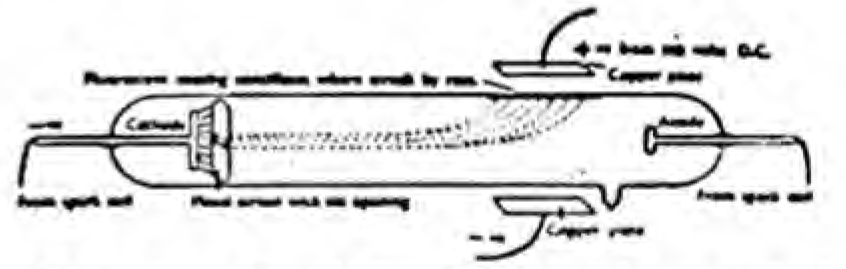


Fig. 1(c). *An electric field also bends cathode ray.* The rays bend towards the positive plate.

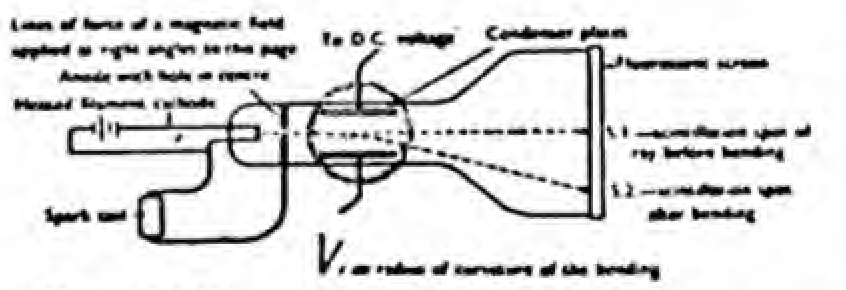


Fig. 1(d). *Laboratory version for exact measurement of degree of bending by magnetic or electric fields of known strength.* The electric field can be set to counterbalance the effect of the magnetic field and thus restore the rays to a straight fall.

N

Later the gaining or losing of electrons was seen to be the basis of valency linkages between combining elements. Valency 1 meant the ability to gain *or* lose 1 electron, valency 2 meant the gaining *or* losing of 2 electrons, and so on up to 7, the highest known valency. We are here getting near to the octave (8 stage) interval of the Periodic Table of the elements!

Radioactivity Provides More Clues

In 1896 Becquerel discovered that in the case of the metal element uranium both the element and its compounds continually give out rays which can pass through paper and thin foil and affect photographic plates. The work of the Curies soon showed that other elements of nearly the same atomic

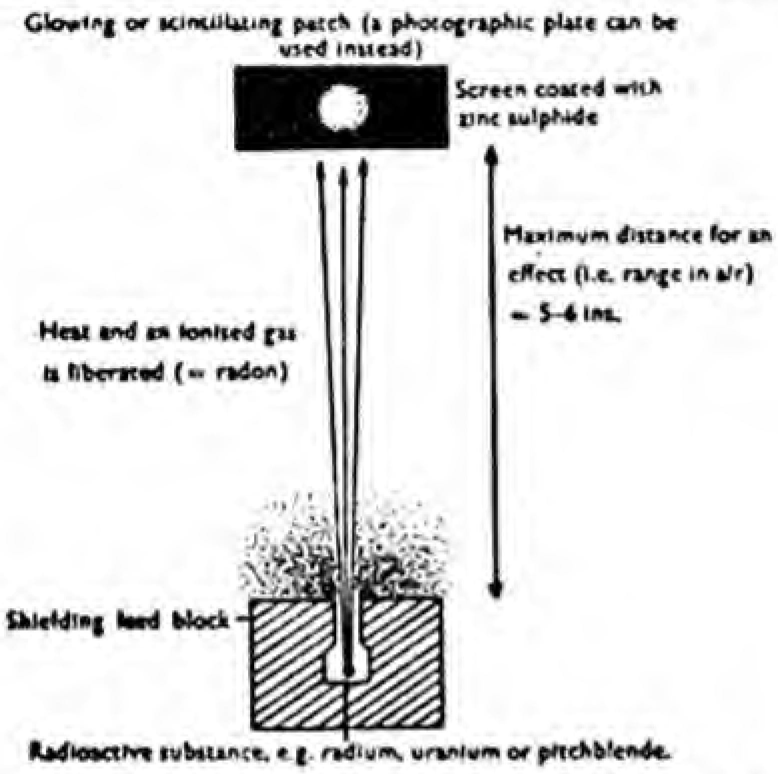


Fig. 2 (a). *Radiation of rays and emanation of gas from a radioactive substance.*

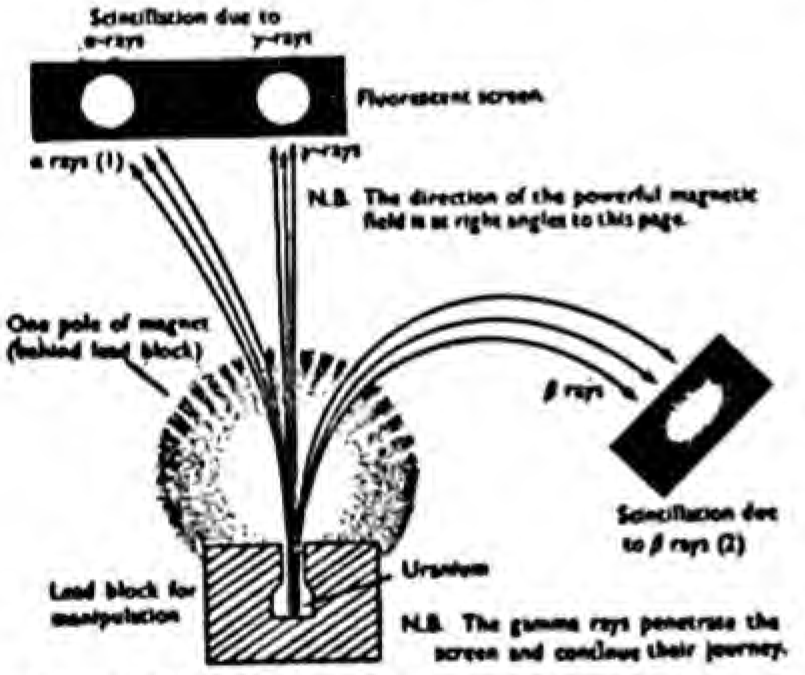


Fig. 2(b). *Rutherford's experiment for separating the radiation from uranium into three parts:* α, β *and* γ.

(1) The bending of the α rays is very slight and is here shown exaggerated.

(2) The β rays are of varying velocities and are opened out into a band by its magnetic field.

weight, such as radium and thorium give off similar rays. For a while these rays, because of their penetrating power, were confused with X rays. But in 1899 Rutherford showed that the radiation from uranium could be split up by means of a magnetic field into three sorts of rays, which he named α, β and γ (Fig. 2b). The course of each stream was traced by the glow produced where it fell on a zinc sulphide screen. The beam which was not deflected by the magnetic field was called the γ ray and turned out to be a more penetrating form of X rays. The β beam, which was the one most deflected by the magnet, later was shown to be of negatively charged particles identical with the electrons of the cathode rays. It was the α stream, weakly deflected by the magnet, that proved to be the most puzzling. The direction of its bending showed it to be made up of positively charged particles. Alpha rays are given off from a number of radioactive substances, but their range (the distance from the source beyond which a fluorescent screen fails to detect them) and their speed at emission (of the order of 18,000 miles per sec.) differs according to the source of the rays.

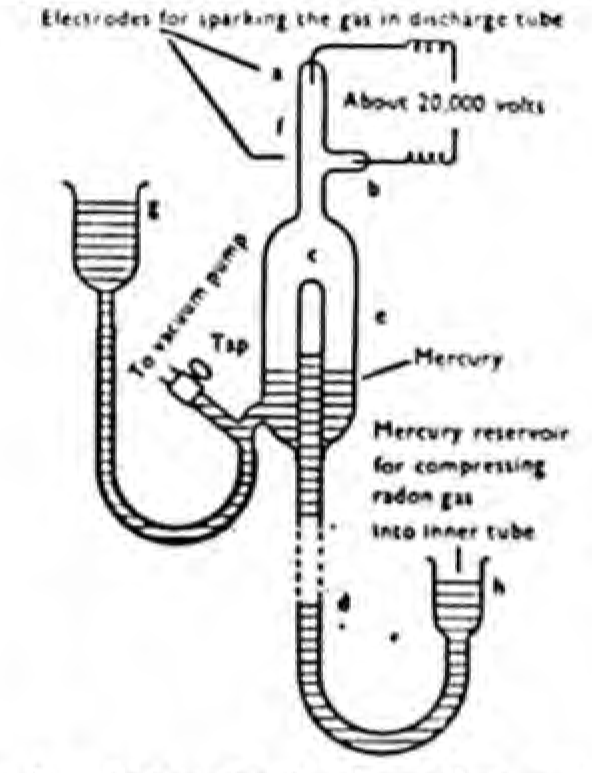


Fig. 3. *Apparatus to show that* α *particles are helium nuclei.*

(a) and (b) Electrodes for obtaining discharge from gas accumulating at head of tube (f).

(c) Very thin walled glass tube (wall 1/100 mm. thick into which the α ray source (as radon) is introduced via (d). (The source was radon gas—radium emanation.)

(e) Highly evacuated tube with thick walls (emptied via the γ tube and a vacuum pump) into which the α particles are able to pass. Helium cannot do this if placed in (c).)

(g) Mercury reservoir when raised drives the gas accumulating in (e) up into the limb (f), where it is sparked, its spectrum proving it to be helium.

(h) Mercury reservoir for compressing radon gas into inner tube.

The elder Bragg, from a study of these ranges and the charge on the particles, which was measured as equal to two electron charges, suggested that the particles were helium ions (i.e. atoms of helium with two positive charges—i.e., lacking two electrons). Rutherford confirmed this with the ingenious apparatus shown in Fig. 3. The alpha particles (from radon gas) could pass through the thin walled inner glass tube. Collected for a few days in the outer tube the product was later driven up into the fine-bore tube and sparked—when the spectrum of neutral (atomic) helium was obtained. The alpha particles when or after they entered the outer tube must each have collected two electrons, becoming atoms of helium. A separate test showed that atomic helium, when put into the inner tube, could not escape through the thin glass wall. Thus the helium obtained in the first test could only have come from α rays passing through the wall of the tube.

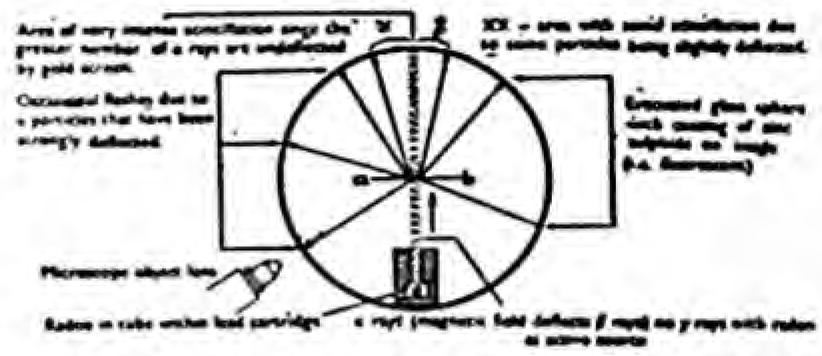


Fig. 4. *Rutherford's apparatus for the investigation of the passage of* α *rays through metal foils.*

(a) (b) = ultra-thin gold-foil screen; in thickness 6 × 10^{-6} cm., it represents about 2,000 layers of gold molecules.

Note: Before use the screen is tested for airtightness, i.e. to prove there are no small holes in it.

When a beam of α rays falls on a fluorescent screen of zinc sulphide the collision of each α particle with the screen produces a tiny spark-like flash of light visible with a magnifying glass. You can see this for yourself if, in a blacked-out room, after resting your eyes, you look through a pocket magnifier at the hands of a luminous watch or clock. With little more technical resources than this Rutherford in 1911 investigated the already known ability of α rays to pass through ultra-thin metal foils, such as of gold, silver, platinum, aluminium, etc. The way he arranged his material is shown in Fig. 4. The surprising thing is that a stream of positively charged particles should to so great an extent be able to pass unaffected through some 2,000 layers of metal atoms without difficulty or disturbance. You will remember that J. J. Thomson had supposed the inter-electron spaces of the atom to be filled with positive electricity to produce the neutral atom. In that case a continuous layer of atoms should act like a brick wall towards positively charged particles, except where an occasional particle might punch its way through by displacing or capturing a negative electron. But this is not the case. Very occasionally an alpha ray is subject to considerable deflection, as shown by rare scintillations all over the surface of the glass bulb; indeed sometimes to a larger angle than 90° (i.e. is "turned in its tracks"). Thus though deflection is rare, when it does occur it can be considerable. All this led Rutherford to conclude that instead of being generally distributed the positive electricity of an atom is densely concentrated in a relatively minute nucleus at the centre of the atom. Leonard from his studies of the penetrating powers of cathode rays had made a more or less similar suggestion as early as 1903. The electrons, which the nucleus holds in virtue of its positive charge, are considered to be scattered around it at relatively great distances. Thus an atom is to be thought of as made up principally of space, a condition that would allow a very large proportion of all α rays falling on a foil to pass through unaffected. The mass or weight of the atom is also concentrated into this nucleus. In the case of the simplest atom, that of hydrogen, the nucleus is found to be 1,837 times as heavy as an electron, yet occupying only 1/10,000th part of the space

inside the atom. This size difference has been compared with that of a fly in a house! (The nucleus of the hydrogen atom has been given a special name because of its fundamental importance. It is called a proton.) Should an α particle when passing through a metal foil chance to come very near to a nucleus, then, since the nucleus carries the mass and the positive charge of the atom, we would expect the α particle to be turned to one side, or even made to return on its course depending on the angle of collision. Rutherford's experiment shows that this is what does in fact occasionally happen.

Rutherford also showed that the amount of deflection experienced by α rays increases with the atomic weight of the metal used for the screen. From this fact a complicated calculation concludes that the charge on the nucleus must increase by one for every successive element in the Periodic Table, the hydrogen nucleus carrying one positive charge.

X-Rays Provide More Clues

When cathode rays are allowed to fall on to an element, either as a separate target or as the anode of the tube, X rays are generated. Moseley in 1913 showed that these could be resolved into characteristic spectra for each element by diffraction through a crystal of potassium ferro-cyanide. The wavelengths of certain lines in these X ray *spectra* decrease regularly with the increase in atomic weight. The decrease is even more closely related to Moseley's Atomic Number, a number calculated for each element, and ranging from 1 to 92 for the naturally occurring elements. The Atomic Number represents the number of electrons in the atoms of an element and it increases one unit at a time from hydrogen (= 1) upward. When these numbers are used instead of Atomic Weights for setting out the Periodic Table (as was in fact done in making the "Ribbon diagram" on page 193) all the small irregularities previously evident in the grouping were found to disappear. The X ray *scattering power* of thin films shows a further fact that each successive element in the Periodic Table has an increase of scattering power indicating the possession of one additional electron.

The Evidence Is Put Together and a Theory Emerges

From such facts the conclusion is reached that the atoms of all the elements must be composed of positive nuclei and negative electrons. One element differs from another in the number of positive charges on its nucleus, which in turn is equal to the number of electrons in the atom. At first, under the influence of ideas borrowed from Newton's system of mechanics, it was considered that the electrons must move round the nucleus in planetary orbits. Thus arose Rutherford's idea of the planetary atom, further developed in 1913 by Niels Bohr when working with Rutherford in Manchester. But in order to explain why, in what is an *electromagnetic* (not a gravitational) solar system, the electrons do not fall into the nucleus, Bohr departed radically from Newtonian mechanics by suggesting that only *certain* electron orbits round the nucleus are possible. From observations of various peculiarities in the radiation of heat by hot bodies Max Planck had recently concluded that atoms only radiate energy in gushes, or quanta. When Bohr in 1922–5 extended his picture of the hydrogen atom to cover the periodic system of the elements his interpretation had the immediate advantage that it could explain why light also is radiated by atoms in stepped amounts, or quanta. The sudden jumping of electrons from one possible orbit to another possible orbit will result in the liberation of a fixed amount of energy depending on which orbits are involved. By quantum theory this amount then fixes the wavelength of the light given out. To agree with the evidence of X ray spectrum lines, the electron orbits are further grouped into sets or shells. The electrons of the outermost shell of any atom are the exchangeable valency electrons. A shell of eight electrons in this region can be shown to be a stable arrangement. Since the gases of the helium-radon series of the Periodic Table, with the exception of helium, have this condition, they show no valency, i.e. are inert, unreactive. Helium itself is a special case, having a stable arrangement of two electrons in a single shell.

In the course of ordinary chemical combination atoms combine together in such a way as to complete between themselves out of their outer shells a total number of eight electrons. Thus arise the octaves of the Periodic Table. Although the planetary idea of atomic structure has now been superseded by a mathematical wave-mechanical description that cannot be visualised as a model (just as Newton's mechanics has been superseded by Einstein's Relativity Theory) the Bohr atom is still a very useful idea, and we illustrate for you on page 199 the structure of the atoms of a variety of elements according to this theory.

More Facts Come to Light

Continuing his painstaking observation of the scintillations produced by α rays Rutherford began examining more closely the features of their passage through gases, as distinct from through metal foils. He carefully measured the various ranges they had in air and other gases, using the simple instrument shown in Fig. 5. In 1919 he was able to show that normally when the source is removed from the screen to a distance greater than the range of all the α particles (= 7 cm. allowing for the effect of the silver foil in front of the screen) scintillation stops abruptly. But when the chamber is filled only with pure nitrogen gas, some very rare scintillations can be obtained at distances as great as 40 cm.! It is as though some process is boosting the α particle effect.

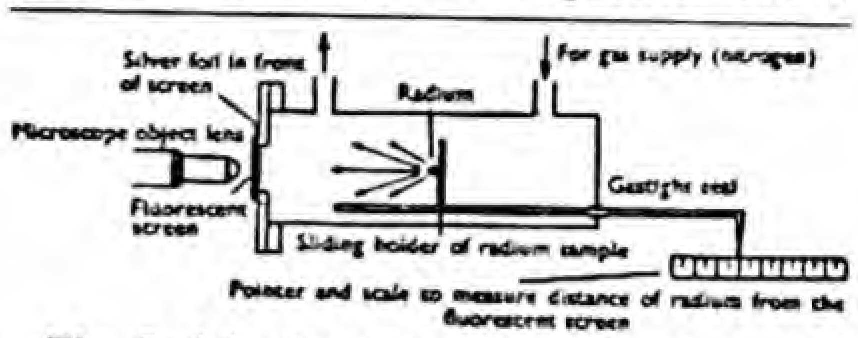


Fig. 5. (a) *Apparatus with which Rutherford first detected the transmutation of atoms by a ray collision (a modification of Crooke's spinthariscope).* Range of alpha rays through gas and silver foil = 7 cm. But when radium is removed to distances up to 40 cm. from the screen occasional (very rare) scintillations still occur. These cannot be due to alpha particles, as the range is too great. They are due to fast protons. (*cutaway of Fig. 5*).

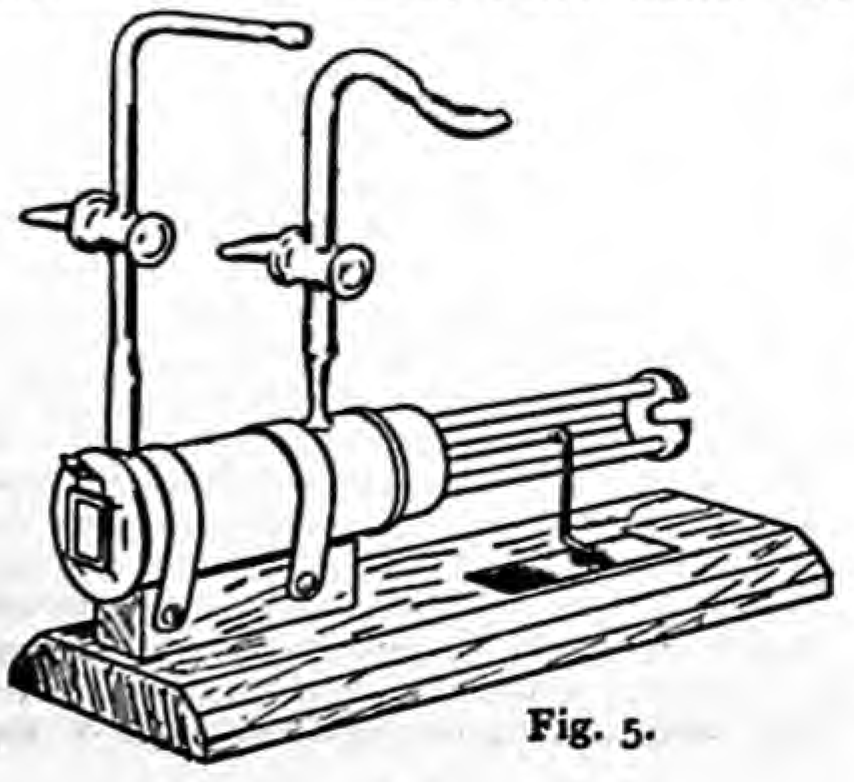


Fig. 5.

The energy properties of these new rays could not be determined experimentally, as it could not be known at what place in the chamber they originated. Rutherford considered it likely that a *head-on* collision between a swift α particle and the nucleus of a lightweight element could result in the α particle approaching extremely close to the nucleus, or even penetrating it. The result of such profound disturbance might be disintegration, i.e. transformation of the nitrogen nucleus into one of another sort. Theoretical considerations suggest that this would be an oxygen nucleus since (although the nitrogen atmosphere was free from atomic hydrogen) the range of the new emitted particles was consistent with their being fast hydrogen nuclei (protons). Nitrogen atom + Helium nucleus (α particle) = Oxygen atom + Hydrogen nucleus (proton) (if calculated on a weight or charge basis). Rutherford later secured a similar emission of hydrogen nuclei from bombarded aluminium on its transmutation into silicon. At about this time the Wilson cloud chamber (used first by J. J. Thomson in 1899) was much improved in its stability and its illumination, so that the water droplet trails left by ionising particles would persist long enough to permit their being photographed. Its operation is synchronised with that of two cameras, so that photographs are only taken when ionising particles are in the chamber. With two cameras, from the stereoscopic effect, the exact placing in space of any track can be worked out.

Nuclear Collisions Are Watched

With this potent new instrument P. M. S. Blackett was able, in 1922, to secure clear photographs (Fig. 6), of collisions between

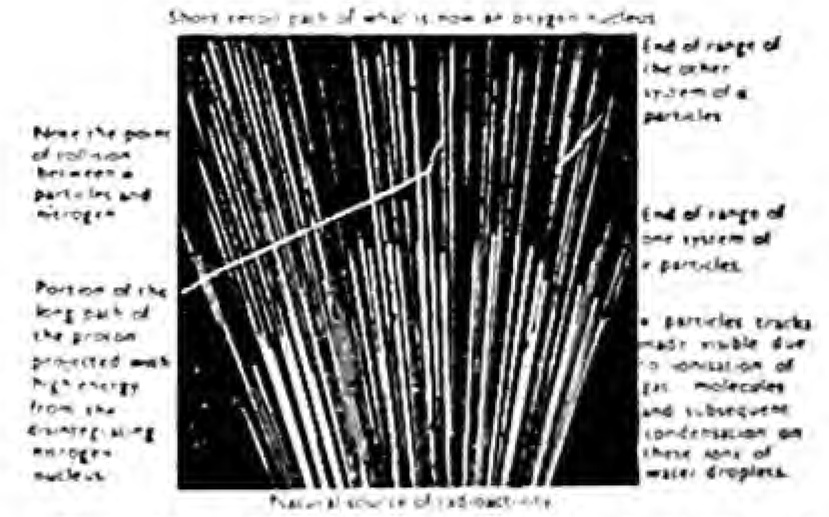


Fig. 6. *Transmutation (disintegrating collision) between an α particle and a nitrogen atom in a cloud chamber* (nitrogen was in the cloud chamber atmosphere). Note the two ranges of α particles due to the use of a mixed source of α particles (i.e. a natural mixture of two radioactive substances each giving α particles of distinctive range).

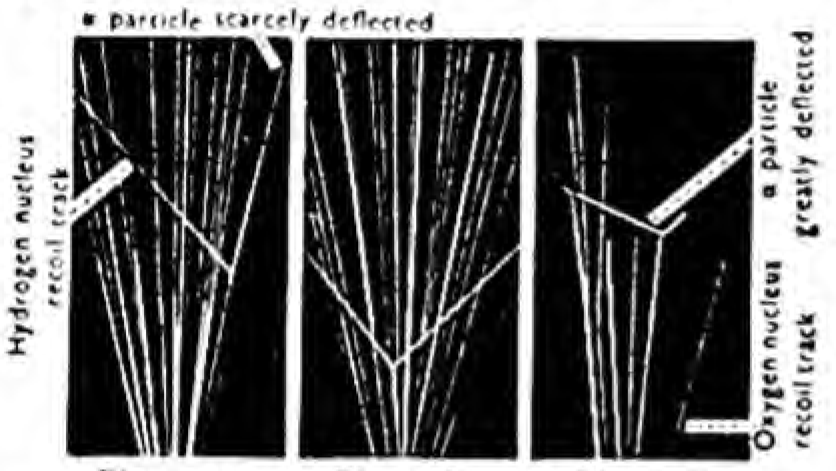


Fig. 7 (a) Fig. 7 (b) Fig. 7 (c)

α particles and nitrogen nuclei. Application of a strong magnetic field to the cloud chamber indicated that the particle emitted after such a collision was positively charged, whilst other measurements of its track confirmed that it was a hydrogen nucleus (i.e. an ionised hydrogen atom)—now known as a proton. Thus was Rutherford's brilliant interpretation of his results vindicated visually.

The proton ejected in this disintegration emerges with great velocity, sometimes at right angles, or at an even smaller angle, to the α ray. This is very different from what is seen in other photographs which Blackett obtained, in the same way, of simple (elastic) collisions between α particles and the nuclei of various gaseous elements, including nitrogen. These collisions are of the same sort as those we have seen are experienced by some alpha particles in going through a gold foil. They are called elastic because the observed effects are in accordance with the mechanical laws of elastic collision that govern the colliding of such things as billiard balls. In these cases a light body hitting a heavy one transfers only a little energy to it, thus making it move only a little. But it is itself deflected or reflected appreciably (e.g. a golf ball hitting a cricket ball). Where the weight difference is less the energy transfer is greater and the struck ball moves more and the striking one is slowed down relatively more. This sort of thing is seen in Fig. 7c, where, after colliding with an oxygen nucleus, the α particle continues for only a short distance on its new deflected course (= the longer arm seen in figure) and the oxygen nucleus recoils only slightly. The result of collision with a helium nucleus of its own weight (Fig. 7b) is that the deflected path of the α particle and the recoil of the helium nucleus are approximately equal. Similar conditions apply to collision with a hydrogen nucleus (Fig. 7a).

Electron Collisions With Atoms in a Gas

Fig. 8. *Cloud chamber tracks of β rays.* The long straight but very narrow path is of a fast beta ray, probably from cosmic radiation. These have ranges much larger than alpha rays and for this reason their ranges are often measured in aluminium where they are much shorter than in air. The shorter (about 1 cm.) curving paths are of slow beta rays ejected from gas molecules by the passage of a gamma ray. Being slower, they are more easily bent by collision with molecules of the gas, to which they more easily lose energy in ionisation, thus producing noticeably thicker droplet tracks.

Fig. 8 shows a cloud-chamber track (= the straight track) of a fast β particle, similar to those in β rays, but here probably derived from cosmic radiation. Notice how very small and widely spaced are the water droplets. This is because fast-moving electrons, despite their considerable energy, have only slight ionising power. Their ionising power is small since they spend so short a time in the field of any other electron in the medium through which they pass. The curving tracks in this figure are of slow-moving β particles. Here the tracks are noticeably thicker and more continuous, and they become more so towards the terminal point of each track. These slow β particles are clearly seen to be more often deflected out of their course with consequently more rapid loss of energy.

Some Problems Set by the Nucleus

We have seen that for any element the Atomic Number represents the number of positive charges carried by the nucleus, which is also equal to the number of planetary electrons. But inspection shows that the Atomic Number is only equal to the Atomic Weight in the case of hydrogen. In other cases the Atomic Number is always smaller than the Atomic Weight, and as we proceed to the heavier elements the difference increases rapidly (Uranium A^t W^t = 238. A^t N° = 92). To make up the nuclear mass to the atomic weight, without increasing the charge beyond that set by the Atomic Number, the nucleus needs to contain additional particles possessing weight but no charge. From the evidence of atomic disintegration the charged particles of the

TABLE TO SHOW POSSIBLE NUCLEAR CONSTITUTIONS

Element	At. No.	At. Wt.	Nuclear Composition	Total No. of Planetary Electrons
Hydrogen	1	1	1 proton ⊕	1 e
Heavy hydrogen or deuterium	1	2	1 proton ⊕, 1 neutron O	1 e
Helium	2	4	⊕⊕ OO	2 e
Lithium	3	6	⊕⊕⊕ OOO	3 e
Lithium	3	7	⊕⊕⊕ OOOO	3 e
Beryllium	4	9	⊕⊕⊕⊕ OOOO O	4 e
Neon	10	20	⊕⊕⊕⊕ OOOO ⊕⊕⊕⊕ OOOO ⊕⊕ OO	10 e
Sodium	11	23	⊕⊕⊕⊕ OOOO ⊕⊕⊕⊕ OOOO ⊕⊕⊕ OOOO	11 e

nuclei of all the elements are supposed to be protons (hydrogen nuclei) of mass 1, charge 1. In 1920 Rutherford supposed that the mass-bearing uncharged particle might be a proton, the charge on which was neutralised by a non-planetary electron. He suggested for it the name "neutron". The table above shows how this idea would work out for a few selected elements. It still remained necessary (1) to discover the proposed neutral particle and (2) to explain why the whole nucleus is, in general, a stable structure. Remember that in all the elements except hydrogen the nucleus contains several or many positive charges—which should repel each other—all situated within a very small space!

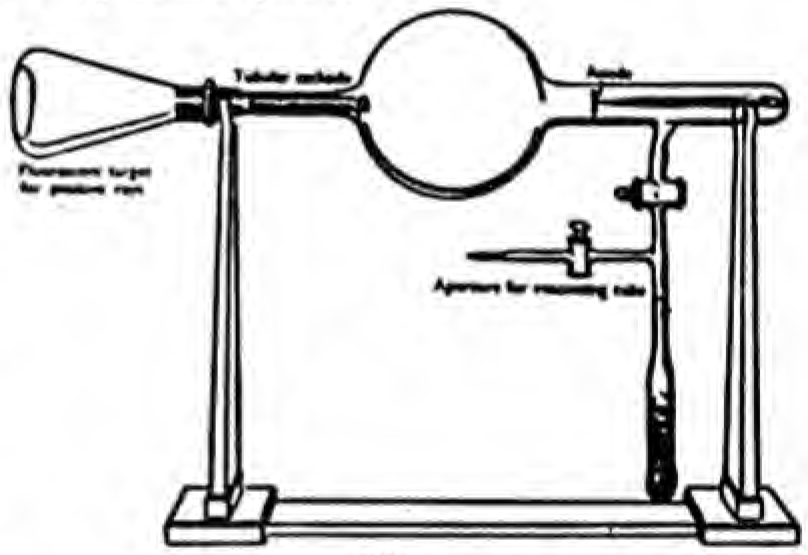


Fig. 9

If the *cathode* of a cathode ray tube is made with a hole through it luminous rays pass backwards through the hole. These are called positive rays, or canal rays. In 1898 J. J. Thomson, using photographic plates to detect the path of the rays, showed them to be deflected by magnetic and electric fields in a way that revealed them to be composed of positively charged particles (Figs. 9, 9a and b). The value of e/m (charge/mass) of these particles can be calculated from the amount of bending they

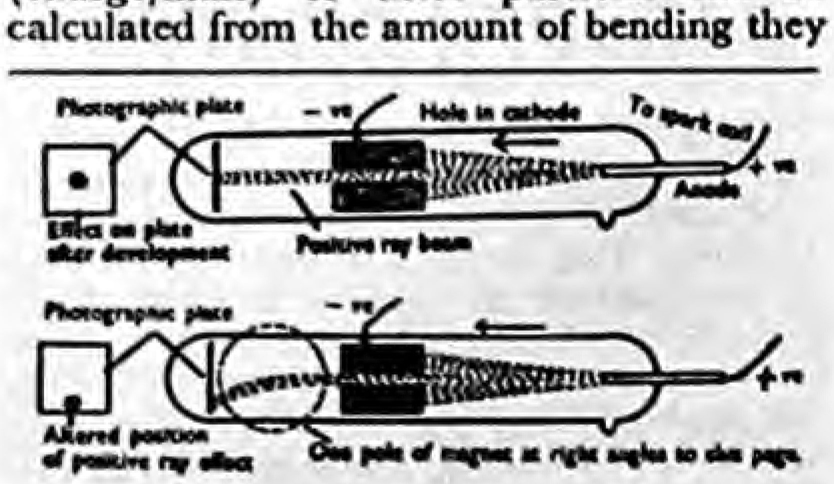


Fig. 9(a) (above) *Positive ray of cathode ray tube.* Fig. 9(b). (below) *Positive ray bent by a magnetic field.*

undergo in a known strength of field, from which it appears that they are positive ions of the gas (at low pressure) in the tube. Whilst making measurements with neon in the tube Thomson (1910) found that the rays when magnetically deflected separated out into *two* streams, which gave two "lines" on the photographic plate. The position of these lines indicated particle weights of 20 and 22. (The lighter particles being faster, are deflected less by the field.) The atomic weight of neon as ordinarily determined is 20·2. Thomson suggested that this figure could be the result of ordinary samples of neon being mixtures of two "elements". Aston developed this positive-ray apparatus into the mass spectrograph (Fig. 10) with which, between 1922 and 1924, he showed that many other elements exist in two or more forms differing in atomic weight.

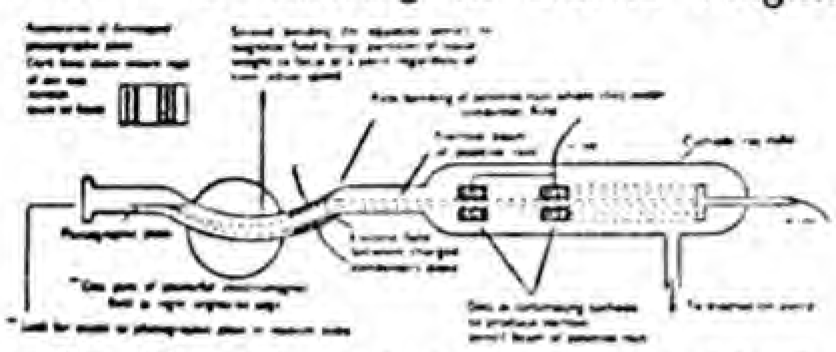


Fig. 10. *Mass spectrometer (Aston's) for isotope separations.*

Soddy had observed a similar situation in the case of two forms of a radioactive element of differing stability both occurring in connection with the same place in the Periodic Table. He called these forms isotopes (= "same place" in Greek). Their existence explains why the atomic weights of elements so commonly prove not to be whole numbers although whole numbers might have been expected on the nuclear theory of the atom. Since the isotopes of any element have the same Atomic Number, their nuclear charges and their planetary electron systems are alike. In consequence they behave alike chemically, and cannot be separated by chemical means. Their difference in atomic weight must be due to differences in the proportions of the neutral particles in the nuclei. Aston also showed that hydrogen (At Wt = 1) contained a heavy isotope (At Wt = 2), to the extent of 1 part in 4,000. In 1932 Urey, by the process of fractionally distilling a large amount of liquid hydrogen, succeeded in isolating heavy hydrogen, which is now known as deuterium (its nucleus = a deuteron) (*See* Table p. 196). Subsequently other workers isolated heavy water (remember water is H_2O). It was found to be 11% more dense than ordinary water. These discoveries were to effect very greatly the development both of ideas and technical resources in nuclear physics.

Clues Now Come Faster Thanks to New and Improved Tools

Technical developments soon made possible the use of artificially accelerated particles to supplement those from natural radioactivity. In 1932 Cockcroft and Walton at Cambridge produced the first artificial disintegration, breaking up the lithium nucleus

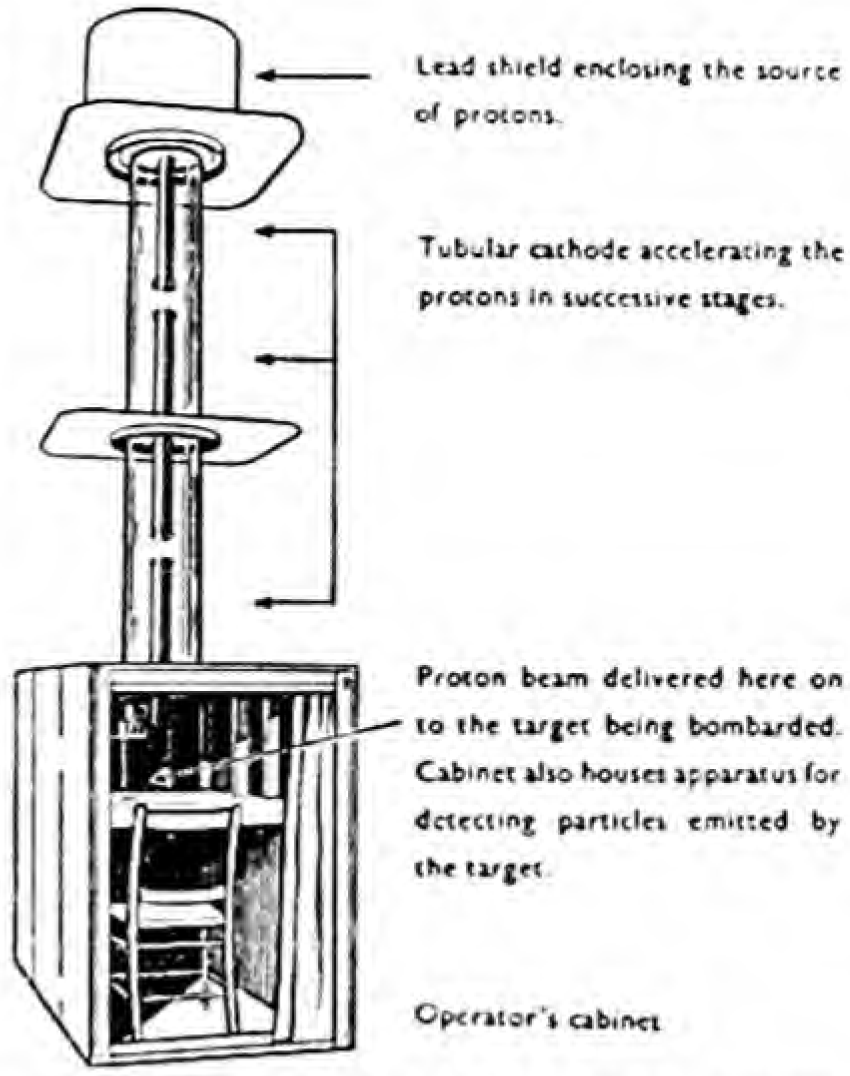


Fig. 11. *Cockcroft and Walton's* 700,000 *volt accelerator.*

into two alpha particles as the result of collision with an accelerated proton. Accelerating machines depend upon the development of high voltages. Cockcroft and Walton got theirs by means of an ingenious arrangement of condensers and rectifiers providing 700,000 volts D.C. This they applied in several stages to a source of protons by means of tubular electrodes (*see* Fig. 11). In the same year Lawrence in America developed in the cyclotron a system of intermittent circular acceleration in a magnetic field (page 192). A limit is set to the possible acceleration in cyclotrons when the accelerated particles begin to approach the speed of light. In the more recent synchrotron (1945) this limitation is overcome by applying frequency modulation to the power supply that feeds the accelerating electrodes. As a result particle streams of *extremely* great energy are obtained. As well as improved "guns" the nuclear research worker now had an increased variety of "bullets". Besides the old α particles and electrons it became possible to have beams of high-speed protons, deuterons, and neutrons, the latter being particles of a new sort to be described later. In addition to using the cloud chamber it was found possible to record the tracks of many of these particles by passing them through the emulsion of specially prepared photographic plates.

More Confirmation of the Nuclear Theory

In 1930 it was found that, when bombarded by alpha particles, the element beryllium gives off rays even more penetrating than the γ rays of radium. In 1932 Chadwick showed that the observed results are most satisfactorily explained in terms of an α particle entering a beryllium nucleus, forming an unstable complex which disintegrates at once into a carbon nucleus and at the same time liberates *not* a γ ray, but a particle of previously unknown kind.

The new particle had the mass of a hydrogen nucleus (proton of mass 1), but carried no charge. It was the neutron, whose existence had been foreseen by Rutherford in 1920. The very penetrating nature of these particles from beryllium is due to their uncharged state, as a result of which they are not subject to electrical repulsion either by electrons or nuclei. Since they produce no ionisation and thus leave no tracks in the cloud chamber, the original confusion with γ radiation is understandable. The Joliots had found in 1931 that the rays from beryllium (not then known to be composed of neutrons) showed an increased ionising effect when passed through paraffin, or other hydrogen-containing material, before entering an ionisation chamber. This strange effect is now known to result from a slowing down of the neutrons in these substances. (Compare the difference in behaviour between fast and slow β particles in Fig. 8.) Slow neutrons are more readily captured by nuclei than are fast neutrons. Thus, in the atomic bomb the large-scale liberation of atomic energy by the chain reaction of a uranium isotope of atomic weight 235, is triggered off by the introduction of neutrons previously slowed by passage through heavy water, or very pure graphite.

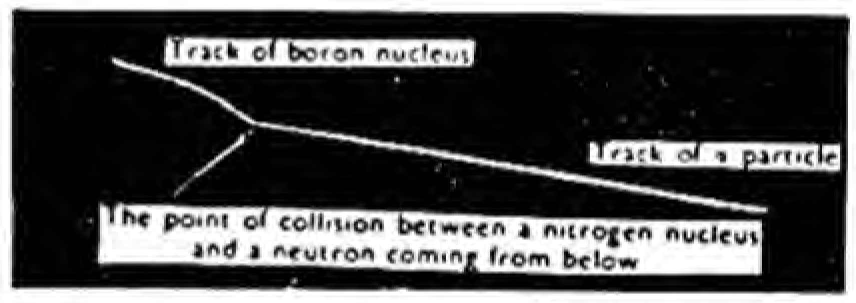


Fig. 12. *Disintegration of a nitrogen nucleus (nitrogen was in the cloud chamber atmosphere) into an alpha particle and a boron nucleus.* The neutrons (coming from below) do not leave tracks, since being neutral they do not produce ionisation of the gases present. But their possession of momentum is revealed by the short and long tracks here not being in line, the upward component coming from the neutrons' motion and direction.

Theories Are Again Confounded by the Facts

Just when the substances of nature looked like being resolved into patterns of protons, neutrons and electrons the picture once again became confused. Not only did fresh discoveries, both mathematical and experimental, reduce the sharp division between particles and radiations, but fresh attention given to the structure of nuclei brought to light a whole crop of new particles—including positive electrons! In 1935 Bohr had shown on theoretical grounds that the elements at each end of the Periodic System are inherently unstable. Many of the heavy ones undergo radioactive disintegration (i.e. flying apart) in varying degrees. The lighter elements, it was shown, must be considered as possessing a tendency towards transmutation by a process of fusion (i.e. running together). Both groups can provide the basis for vast energy production in the course

of these nuclear disturbances. Yukawa, in the same year, was led by other theoretical considerations to predict that in the course of such nuclear disintegrations part of the *force* involved in holding together the particles of the nucleus would be set free as other *particles*! These would have mass intermediate between protons and electrons. Two years later, in 1937, investigations into the effects of cosmic radiation (*see below*) revealed the production, both in cloud chambers (Fig. 13) and in photographic plates, of such particles. They are formed only when atoms are bombarded by rays of *very* great energy, and they were named mesons. Mesons have also been produced artificially in the cyclotron. Careful exam-

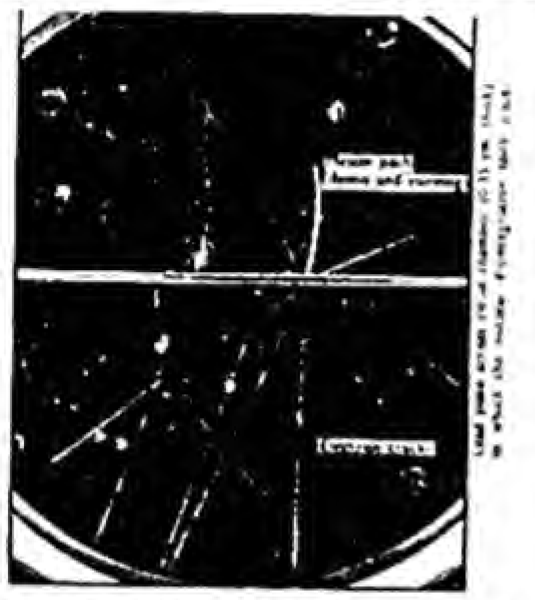


Fig. 13. *Nuclear disintegration in cloud chamber due to cosmic rays showing production of a meson.* The radius of the curvature (due to a magnetic field) of the dense track is not curved if particle is a proton having amounts of energy indicated by length of track. Further inspection indicates that the mass of the particles = 200 mass of an electron. Examples are known where the charge carried is + ve, in other cases − ve.

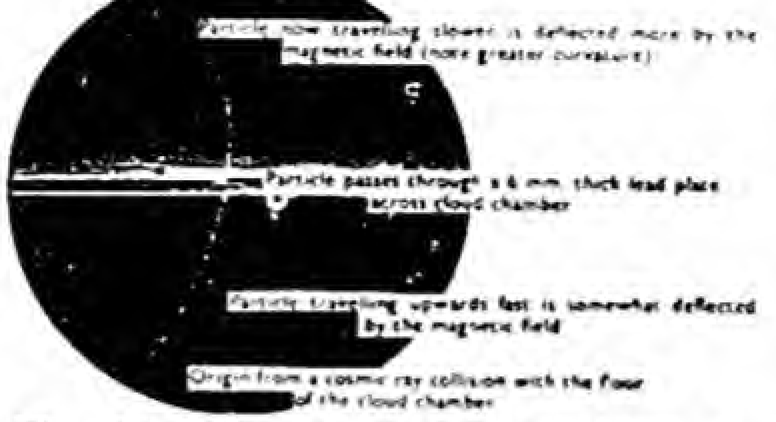


Fig. 14. *The first discovered positron as a secondary product of cosmic ray activity in a cloud chamber. Note:* There was a magnetic field perpendicular to the face of the cloud chamber. The direction of curvature of the track indicates that the particle carries a + ve charge, otherwise it has properties of an electron.

ination has shown that mesons of different masses can occur. Those best known are about 300 times the weight of an electron (protons, remember, have nearly 2,000 times the mass of the electron). Positive and negative forms of mesons have been seen!

We have already seen that during radioative disintegration electrons of high velocity (β rays) are shot out of atoms. The great velocity with which they emerge (from 62,000 to 180,000 miles per sec.) shows they have come from the *nucleus* and not from the planetary orbits. This is confirmed by the fact that a nuclear disintegration in which a β ray is emitted always produces a new nucleus of atomic number one unit greater than the original. This is what would be expected if the *nucleus* had lost an electron. In 1932 Anderson showed that cosmic radiation occasionally liberates *positive* electrons (called positrons) from nuclei lying in its path (Fig. 14). Often these positrons are liberated as members of what are called positron/electron pairs (Fig. 15). Presumably these nuclear electrons exercise some role of binding together the other nuclear particles.

The more precisely we seek to describe what the world is made of, the more complex and incomprehensible the problem seems to become! It is now more than ever evident that matter is a remarkable and still mysterious phenomenon. Yet though its properties have proved to be too complex for picturing in any atomic model, its behaviour does seem capable of being described in mathematical equations.

In this account of the last sixty years of research in atomic physics we have been able to show little more than the outside of the edifice of knowledge which patient and ingenious research has erected.

Conclusions that now seem obvious and inevitable seemed contradictory, or even crazy, at the time when the discoveries were first made. It is for that reason you will find adjacent to this account a box setting out the different names (synonyms) that were given to the same happenings before experimental demonstration made clear beyond doubt they were one and the same.

Fig. 15. *Cosmic ray production of two positron electron pairs in the wall of the cloud chamber.*

Types of Ray encountered in the study of radioactive behaviour.

Alpha rays are made up of particles. They are bent by a magnetic field in such a way as to reveal a + ve charge on the particles. Weight and charge show that the particles are helium ions (i.e. the nuclei of helium atoms) with a + + ve charge.

They have great energy (being comparatively heavy for atomic particles) although rather slow moving (18,000 miles per sec.). This speed is about 100,000 times the velocity of gas molecules, but it varies somewhat according to the emitting source. It is because of this that rays are found to differ in range according to the means used to obtain them. Because of their larger mass they can penetrate the surrounding electron orbits of other atoms without suffering any deflection and *may* approach very close to the nucleus, when the α particle, due to repulsion by a like charge will experience a sudden change of direction (deviation or deflection). They ionise a gas through which they pass. They are absorbed by 5/1,000 in. of aluminium or by a sheet of writing paper. They can penetrate it through a gold foil 2,000 atoms thick. Their range in air is up to 8 cm. but it varies according to the source of the alpha particles.

Each particle falling on a zinc sulphide screen produced a scintillation.

Beta rays are made up of particles. These rays are bent by a magnetic field in such a way as to reveal a negative charge on the particles. In weight and charge they are alike to the particles of the cathode ray. They are electrons.

Electrons have very little weight, though as β rays they may travel at great speeds, varying from 62,000 to 180,000 miles per sec. (i.e. at their fastest they approach the speed of light). Fast electrons may have sufficient energy to penetrate the surrounding electron orbits of an atom. They are then deflected from their original course by the positive charge of the nucleus. They are more often turned through larger angles than is the case for α particles, since they have a much smaller mass. Slower electrons are more easily deflected, and in consequence more quickly lose their energy. Electrons ionise a gas through which they pass. They are able to penetrate $\frac{1}{8}$th in. of aluminium or 2 mm. of lead.

When a narrow cathode ray beam is passed through thin metal foil the rays act like X rays (as if they were not particles but a radiation) and are diffracted giving an appropriate pattern on a fluorescent screen. They also show reflection off the face of a single nickel crystal. This means that beams of electrons can act as if they are made up of waves of definite wavelength as is the case for light (compare the electron microscope). Cathode rays are also found to cast shadows of objects in their path. This shows how difficult it is to distinguish usefully between particles and radiation—the latter itself measured as photons or quantium "packages"!

When (as a cathode ray) they are stopped by any solid object they set up X rays (an analogy would be machine-gun bullets striking a target and producing sound waves).

Each particle does not produce scintillation on a zinc sulphide screen, but the beam as a whole does produce scintillation.

When travelling slowly electrons are easily absorbed by atoms, even by those of gases.

X rays are electromagnetic radiations of various wavelengths intermediate between light rays and γ rays. They are not deflected by electron or magnetic fields.

Unlike light rays they have considerable penetrating power towards a metal screen. Hard X rays (of shorter wavelength generated by *very* high voltages and very low pressures in cathode ray tube) can penetrate up to 1 foot of solid steel. Softer rays penetrate less, and by suitable exposure can be used to make metal objects in the body (e.g. stomach) appear as dark shadows (i.e. as if opaque) on a screen. They show little trace of reflection at surfaces, and they are not refracted like ordinary light. They may be resolved into a spectrum by reflection from a crystal (more correctly, by diffraction due to the regular structure of the crystal).

X rays will fluoresce on a screen of platinum barium chloride.

Gamma rays are a form of radiation. They are not streams of particles. They are unaffected by a magnetic or electric field.

They are more penetrating than X rays, to which they are akin. They will pass through 1 ft. of iron or many inches of lead, and are only surpassed for penetrating by cosmic rays. They pass through much greater thicknesses of aluminium than β rays will do.

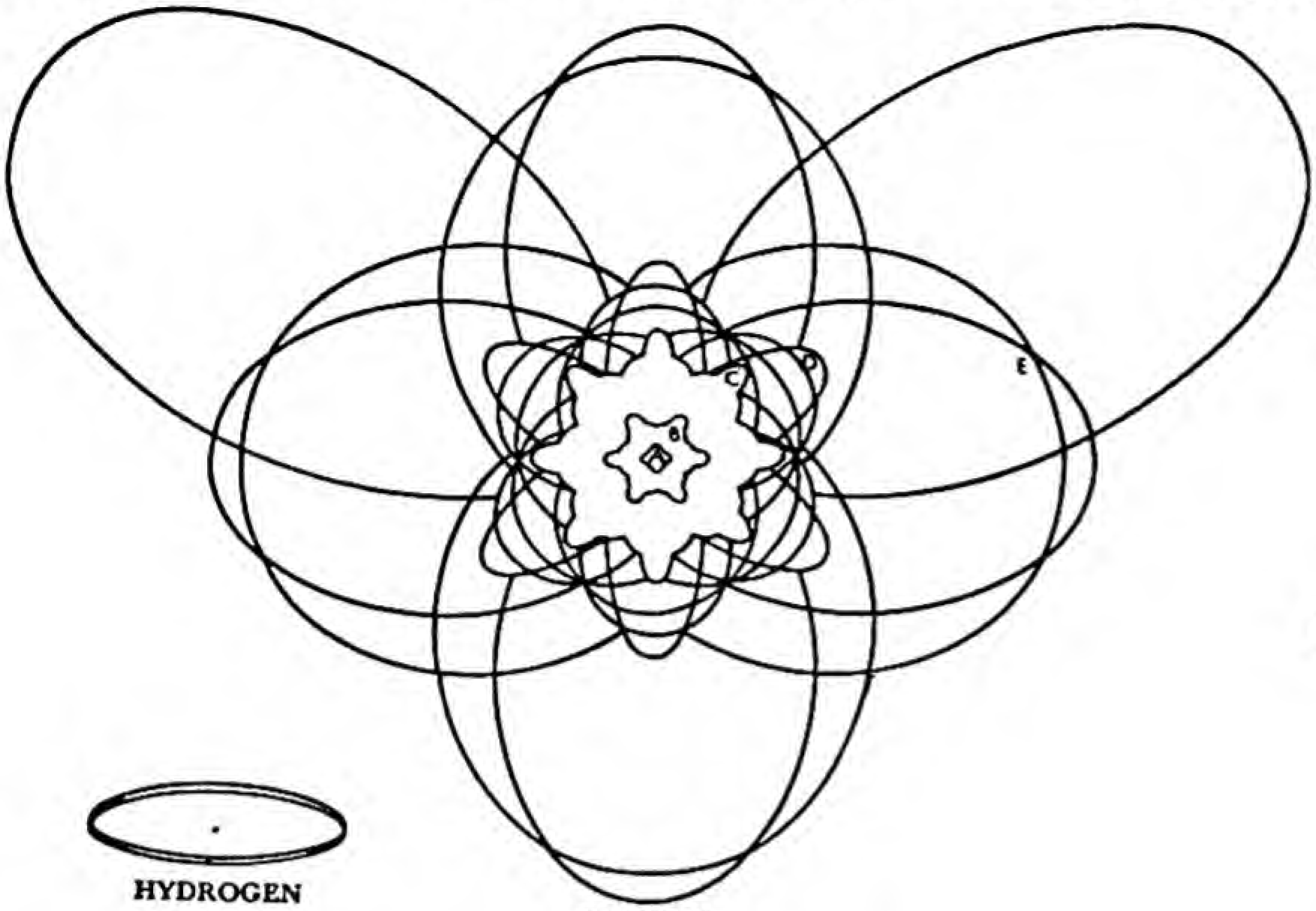
They ionise a gas through which they pass since they "knock out" (by energising them) some of the planetary electrons of the gas atoms, which electrons in their turn produce more ions from other atoms. Thus the cloud chamber tracks of gamma rays are very unlike those of ionising particles. They cause a diffuse, fluorescent screen to glow.

Cosmic rays. An extremely hard, penetrating radiation (i.e. of shorter wavelengths than γ rays) that can be detected by electroscopes and cloud chambers. These rays penetrate thick lead plates that would absorb gamma rays, though some parts of this very variable radiation may be absorbed by 10 cm. of lead. They are thought to enter the earth's atmosphere from outer space. In the earth's atmosphere these primary rays are largely converted into secondary rays of less energy, such as mesons, positrons, high-speed electrons, etc. The intensity of cosmic radiation diminishes between the equator and the poles. This is believed to be due to deflection by the earth's magnetic field and would suggest that the primary cosmic rays reaching the earth are of positively charged particles, probably protons.

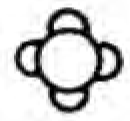
Some equivalent names (Synonyms as used in atomic physics.

α rays	— α particles: they are helium nuclei —helium ions.
β rays	— β particles: they are fast electrons.
Deuteron	— heavy hydrogen nucleus.
Electron beam	— stream of β particles.
Photon	— quantum (package) of light energy: particle of light.
Positive rays	— canal rays: they are of ionised gas molecules.
Positron	— positive electron.
Proton	— normal hydrogen nucleus: it is a hydrogen ion.
Radium	— radon: it is the highest member of the series of inert gases in the Periodic Table of the elements. It is given off during the radioactive breakdown of radium, and is itself radioactive.

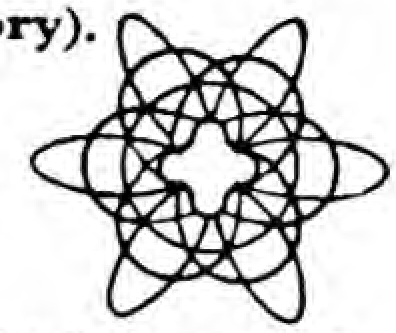
THE STRUCTURE OF ATOMS (models of electron orbits according to Bohr's theory).



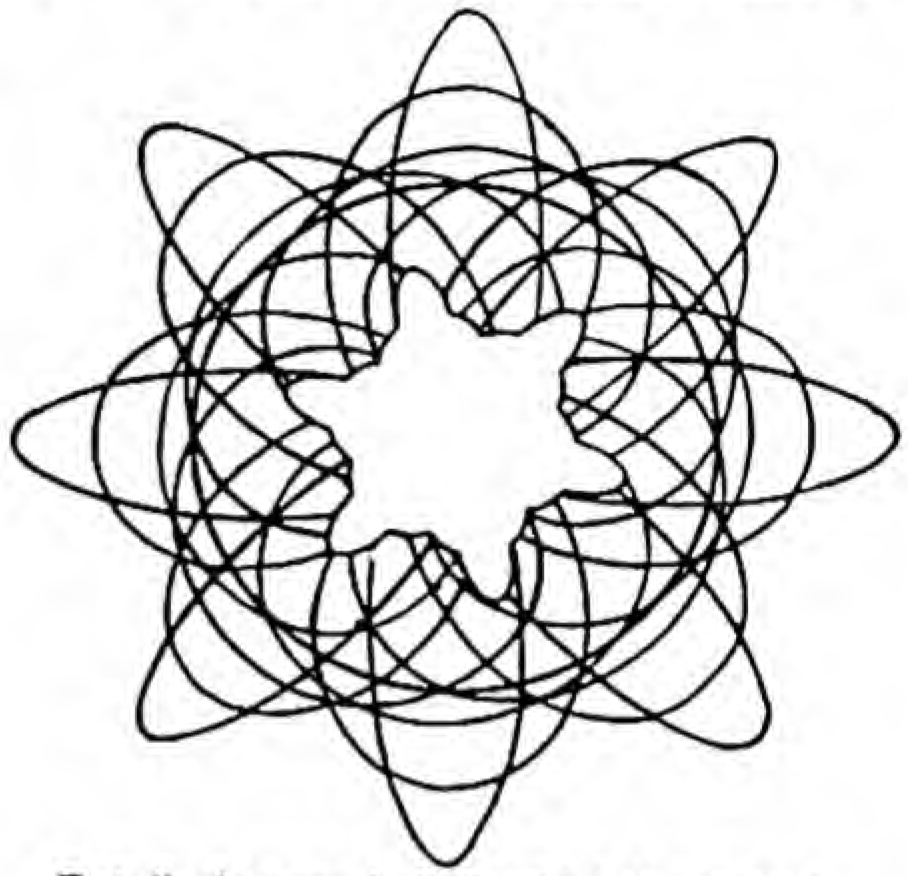
RADIUM



Detail of inner shell A which is inside B

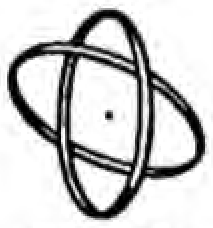


Detail of inner shell B which is inside C



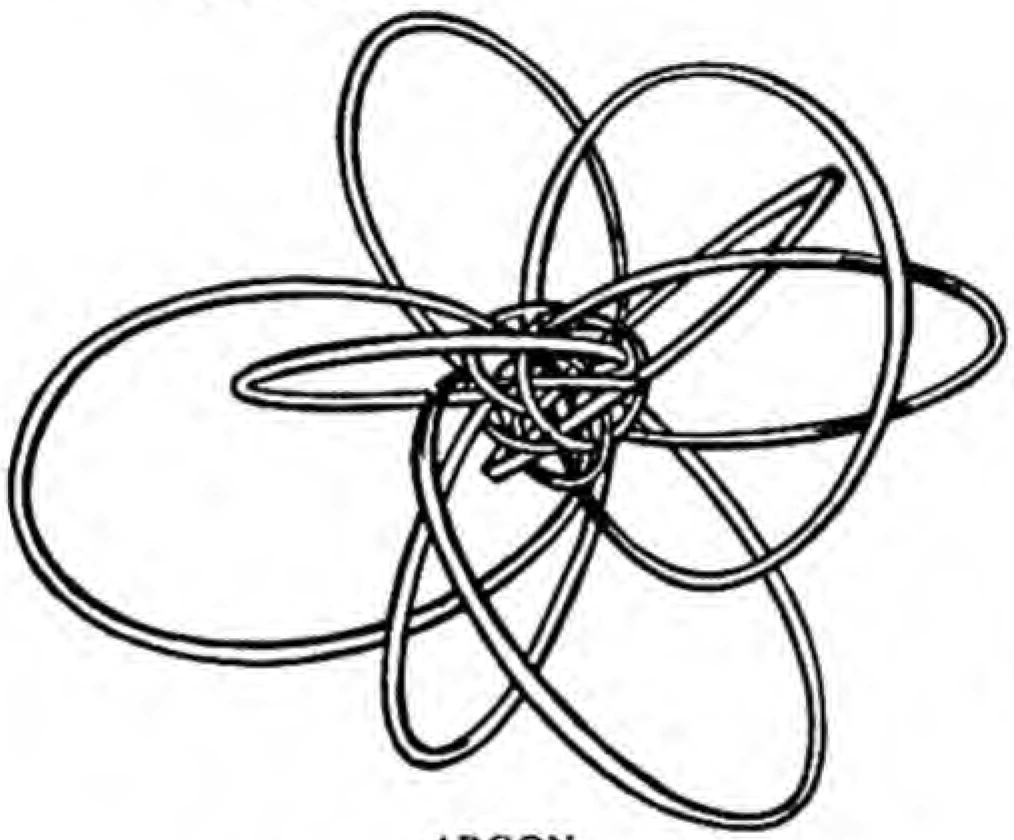
Detail of inner shell C which is inside D

HYDROGEN

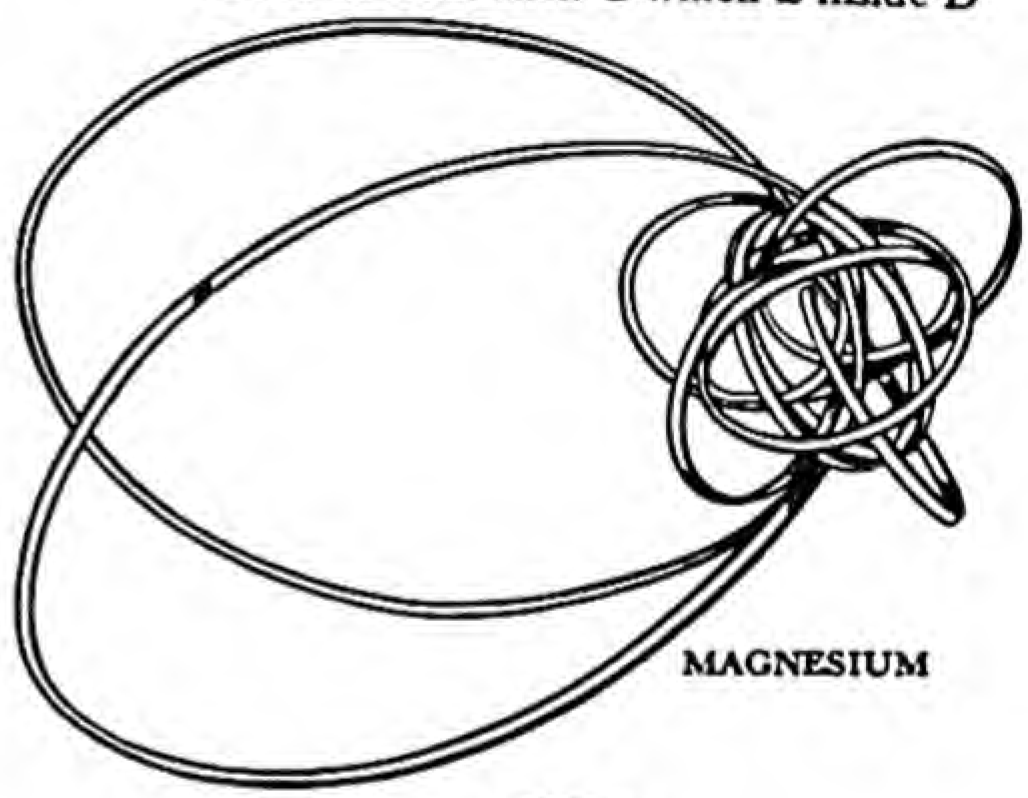


HELIUM

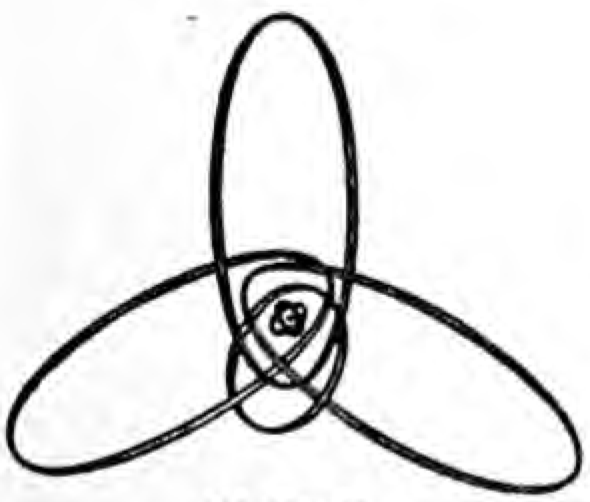
LITHIUM



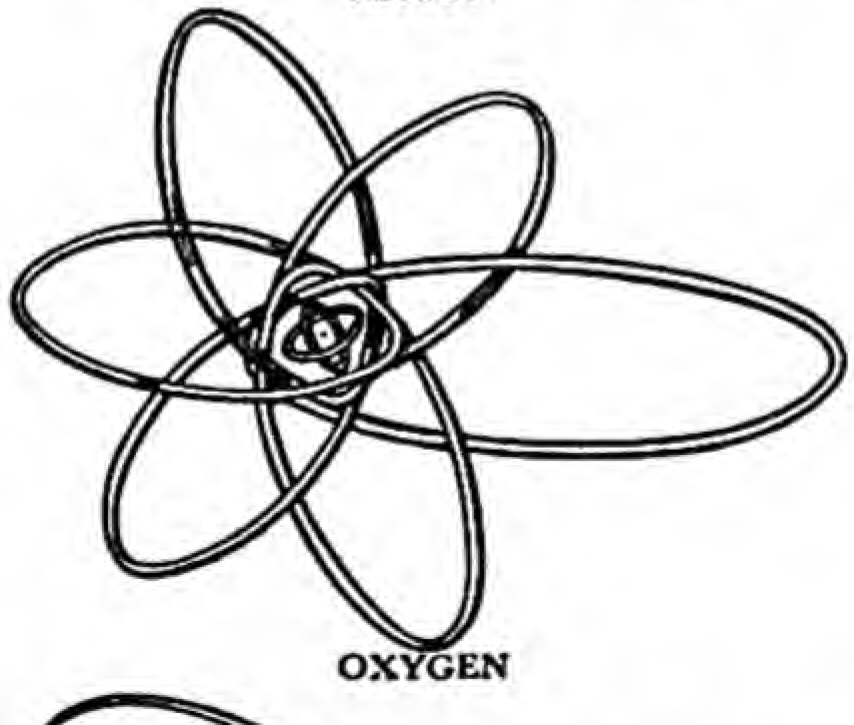
ARGON



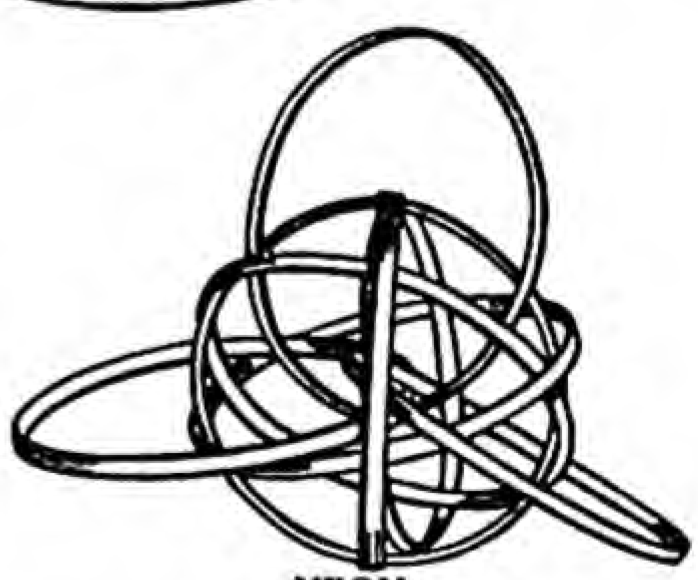
MAGNESIUM



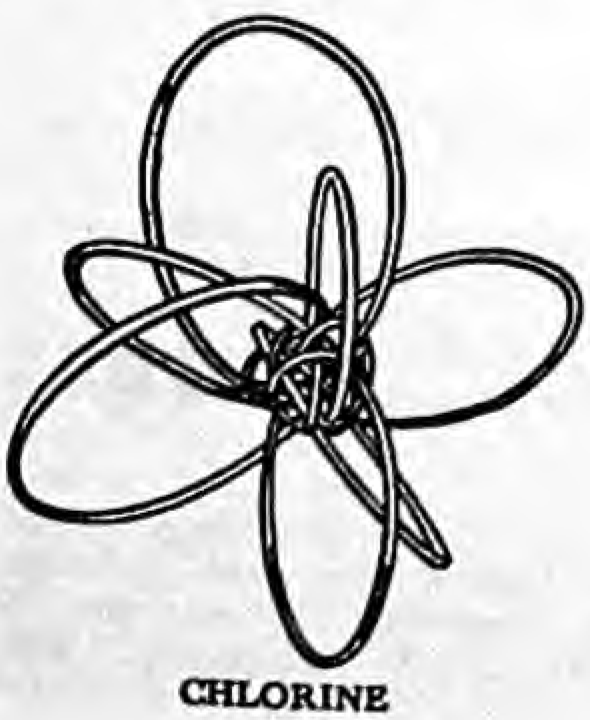
CARBON



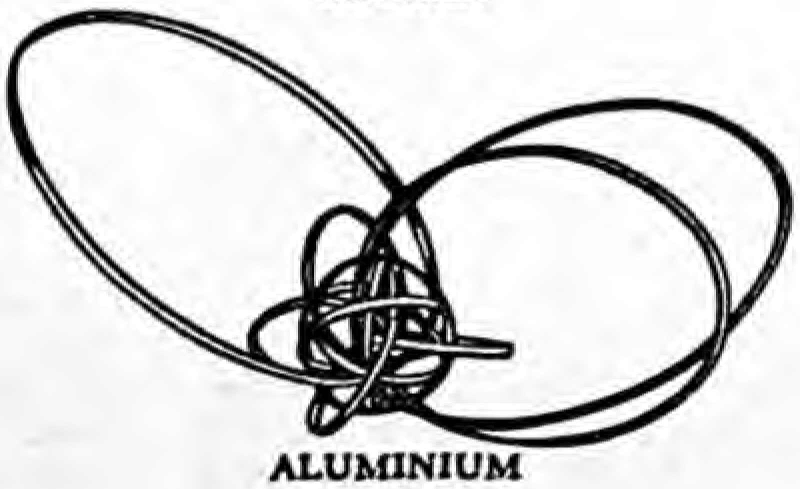
OXYGEN



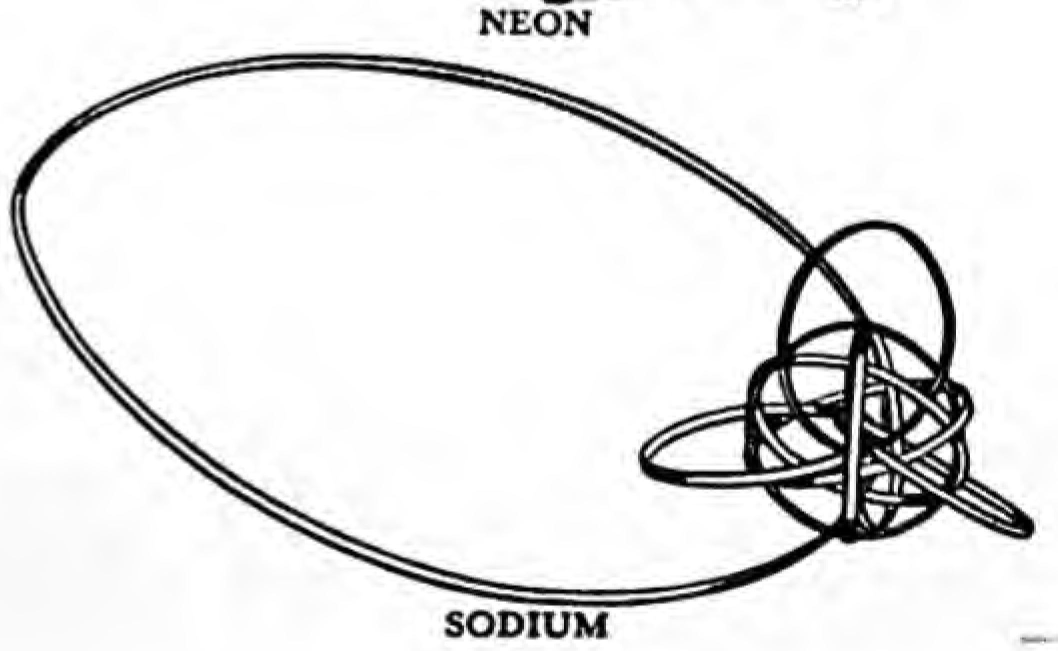
NEON



CHLORINE



ALUMINIUM



SODIUM

ECOLOGY

Ecology is the new approach to natural history, in contrast with the old which chiefly concerned itself with the private lives of birds and beasts. It is the study of the inter-relations that exist between plants and animals as they live together in the wild. It includes a study of their geography (distribution), of their biology (construction in relation to feeding and movement, and to the struggle to survive), as well as of any special points that arise out of interaction between species (e.g. symbiosis, a form of mutual aid, as in a lichen, where a fungus and an alga live together more successfully than either can do apart).

The name of this subject need not worry you. It is from the same origin as economics. Both words come from the Greek word "Oikos", the house. Ecology by its name indicates that it is the study of household affairs. It is the examination of the social relations of living creatures in nature.

Ecology rests on the idea of community. Plants and animals in the wild do not occur at random, but are members of complex units. As in human communities, so in plant and animal societies, all individuals have not the same abilities, all have not the same needs, all do not occupy the same position. Each sort fits in with the others like one piece fits into the complete pattern of a jigsaw. Wild communities that we can readily recognise include woods, marshlands, swamps, and seashores in their various sorts. In all these we find characteristic animals, arranged in distinctive groupings.

Ecology is usually divided for convenience, and only for convenience, into plant and animal ecology. We will take plant ecology first.

Since plants are more or less fixed, the first approach of the plant ecologist to his material usually takes the form of mapping its distribution.

Descriptive Ecology of Plants

1. *Sampling and Composition*

The student must learn to identify and name the kinds (or species) of plants that occur in the community he studies. This is done by using a flora, or botanical handbook designed for this purpose.

2. *Structure*

When we study the architecture of nature, for example, that of woodland, with its tree canopy, under-shrubs, climbers and ground layer (*see pages* 40, 41), our study must include what is below, as much as what is above the ground. That is to say it must include the investigation of root as well as branch systems.

Experimental Plant Ecology

By applying or withholding influences in test areas in the field (for example by felling, mowing, manuring, watering or even fencing a test plot), we can watch the consequences that follow any changing of the local conditions. In this way we find out how the various local conditions influence the growing plants, and reveal the effects which each produces.

Very accurate measurements, with special instruments, of the local climate and of the peculiarities of the local soil also enables us to understand more clearly the conditions under which the vegetation is growing.

Laboratory investigation (which as well as including anatomical investigation may involve the experimental cultivation and propagation of species found in the community we are studying) will tell us a great deal about the plants themselves, their needs and their effects on one another.

Theoretical Plant Ecology

The idea that particular factors or influences are fundamental in shaping and controlling vegetation has proved to be a most useful one. Many groups of factors are recognised.

1. *Climatic factors*

These include temperature, rainfall, sunshine exposure, etc. You will notice elsewhere in this book how different communities, like desert, steppe and woodland, are related to particular kinds of climate.

2. *Soil factors*

The kind of soil, its water content, the abundance in it of mineral foods available for the growth of the plants are all included here. On salt-marshes (*see page* 181) soil conditions vary with the extent to which the mud has been built up to high-tide level, and with this the composition of the vegetation and the kind of animals that can be found varies also, producing recognisable zonation (i.e. orderly division into different types of community).

3. *Factors of competition*

A community includes species with different forms of growth—tree, bush, herb; and with different physiological requirements. (Physiology has to do with the functioning of a creature, e.g. a plant's requirements for water or salts from the ground, and of course also for light.)

Tropical Rain Forest (*see pages* 40, 41) shows a very-well-marked structure resulting from competition between species of differing habits of growth. This produces variation in intensity of many factors within the community. Light intensity diminishes downwards from the top, as the light passes through, and is partly absorbed by successive layers of the canopy. Thus the lower species have to be kinds that are more shade tolerant than the upper ones. The humidity or dampness of the air, on the other hand, diminishes upwards so that the plants in the upper canopies have to resist condition likely to dry out their leaves much more than those in the steamy atmosphere lower down. The animals specialized to certain food plants or to certain backgrounds show a similar layered distribution.

4. *Historical factors*

These include what man has done (for example when he has felled trees) as well as the effects of ancient geological processes (for example the opening of the Straits of Dover separating Britain from the Continent). Historical factors may be involved in the local availability, as a result of protection or planting, or parent plants from which seeds may come for the colonization of bare spots in the community. The deciduous woodland (*see page* 152) in Britain has been enormously influenced by historical factors.

Man has largely felled the trees that formerly covered Britain. The result is extensive grasslands which are maintained by putting on grazing animals to keep down bushes. Man may plough up the grassland to produce a seed bed in which to start his crops, incidentally starting a community of weeds peculiar to cultivation! Continued cultivation (soil disturbance) is necessary to keep the ploughland in existence (i.e. to prevent reversion).

Some Other Theoretical Concepts of Plant Ecology

Concepts are ideas that help to tie together the observations that we make in studying anything. Three are of great importance in connection with vegetation.

1. The idea of *dominance* (which, by the way, has nothing to do with the idea of dominance in heredity). Dominance is the assertiveness, rather than the abundance, of certain members in a plant community. In an oak wood the oak trees are dominant, though primroses and bluebells may be more abundant. Being dominant the trees set the conditions of life for the things that grow beneath them.

2. The idea of *zonation*. Here we note that within a community there are recognizable bands, or levels of living conditions where species peculiar to them may be found. You have had a good example of this on the seashore in the zonation of seaweeds against the tideline (*see page* 180).

In the cool temperate forest region there is zonation in relation to climate. We find deciduous leaf-dropping forest trees are dominant when the climate is not extreme. Where it is extreme, and is characterized by short cool wet summers evergreen coniferous forest takes its place, though the occurrence of this evergreen forest is also related to soil conditions. Cold wet conditions of climate, in time, make any soil acid, causing it to degenerate. In this degenerated state the soil conditions are better endured by coniferous species than by oak and ash or beech.

3. The idea of *succession*, or change with time. Vegetation is always changing, though we may not live long enough to notice this very distinctly in more than an occasional example. Bare areas at first become colonized by occasional, widely spaced plants called pioneer plants. Sooner or later the vegetation closes up and pioneer communities are established. In time these become more and more mature as the pioneer species are ousted by later comers. The change is always a little at a time, until in the end the result is a climax community that can be shown to be in close (i.e. stable) relationship to the local climate. For example the steppe lands, prairies, pampas and veldt, all have climax vegetation controlled by the slightness of the rainfall which is insufficient for the growth of trees. The great forest types, tropical rain forest, deciduous and coniferous forests of temperate lands (which you see illustrated on pages 40, 41 and 151–153) are climaxes related to differences in rainfall distribution and to temperature differences.

You may have seen an instance where the bare soil of a garden has been neglected. At first it starts to grow scattered weeds, then becomes a patch of tall grasses, later, if the garden is deserted long enough, bushes appear, and the result is scrub. In the long term the scrub may turn into a woodland community.

Another example of succession is seen on the seashore. Here the building up of salt marsh by the deposit of mud from the tide results in successive colonization by groups of specialist plants which are related to the height attained by the mud. In this instance the succession of the plants is also represented by their zonation. But that is not always the case, e.g. zonation on a mountainside has nothing to do with succession, being the result of differences in climate at different altitudes.

Descriptive Ecology of Animals

Animals, in the main, are on the move all the time, when compared with plants, which stay put. Therefore the approach of the animal ecologist is quite often very different from that of the plant ecologist.

We can divide the subject again into several parts.

1. Sampling is necessary to find out the composition of the community, what insects, what birds, what lesser creatures, what mammals occur there. They have to be caught by various means, and then identified, using reference books for the various groups.

2. The abundance of these species in individuals has also to be found out by population counts (taken at different times of the year, taken in different years, as well as in different places, where a similar community is found to exist).

3. The recognition of food relationships can only be the result of long and careful observation of the behaviour of the various species. Here one must determine which is the predator (that is to say, the eater) and which is the prey (that is to say, the eaten). We look also for scavengers, which eat up dead bodies or excreta, and note those animals which prey on vegetation rather than on other animals (that is to say are herbivorous or vegetarian).

Experimental Animal Ecology

Here the approach is very like that of plant ecology previously mentioned. One must add, however, the important results that may come from the enquiry into the contents of a creature's crop and from the examination of pellets and faeces.

Theoretical Animal Ecology

Because of the difference between plant and animal communities, animal ecology introduces us to further theoretical concepts.

1. The idea of *food chains*. We trace back the food of an animal not only in terms of what it eats itself but of what its prey has eaten in its turn, and so on back and back until we find the beginning of the chain in the vegetable world.

In the veldt the zebra eats the grass, and the lion eats the zebra, though both may die and be eaten by hyenas, and all of these animals by their excretions of their bodies in decay return back into the soil the substances from which fresh grass grows in another season.

In the tundra, the arctic fox preys on the arctic hare, which in its turn feeds upon such scanty vegetation as it may be able to find (*see page* 45).

In the sea the herring has a food chain starting in the plankton where small animals eat small plants and are themselves eaten by larger animals. This may continue until the larger plankton animals become the food of the herring. In its turn the herring may become the food of larger fish or of man himself.

2. The idea of ecological *niches*. This is the notion that in an animal community a creature often occupies a position special to itself, to which it is adapted in its bodily structure or by its physiology (*see pages* 143–150). Niches may sometimes be based on peculiarities of the food chain. In the veldt the zebra eats the grass, but the giraffe grazes the leaves of the tree shoots. They thus do not compete with each other for food. Or the niche may be based on a protective colouration, the creature being less noticeable living against its normal background. This is seen in moths and birds in tropical and in temperate forests. Occupying a special niche serves somewhat to conceal them from their enemies. The zebra and the tiger alike in their natural habitats are made less, *not* more, conspicuous by their vivid striped patterns.

3. The idea of *fluctuating abundance*. In animal ecology this is a most important concept.

Some of these fluctuations in abundance seem to be induced by the climate, either because of its variability through the seasons, or because of its variations from one year to another.

In the Arctic Tundra (*see pages* 44, 45) there is a seasonal increase in the abundance of insects and seashore life. This is reflected in the arrival in the season of abundance of migratory birds which uses these creatures as their food.

Other fluctuations seem (like the economic cycles of boom and slump in human society) to be self-developing, that is to say, to arise from some feature of the system—some hidden instability. It sometimes may be due to overpreying. The predator feeds so lavishly as to produce a scarcity of its prey. When the prey becomes scarce, the predators themselves, through starvation, become fewer in numbers. When they become fewer in number the prey has a chance to increase in its abundance, and, with a lag of time, the abundance of the predator will start once again to increase.

You will see therefore that ecology is a most exciting subject. Going, as it does, far beyond the simple observations of geography and natural history it gives life to the bare bones of anatomy that the laboratory examination of isolated animals or plants discovers. It not only offers *you*, if you take it up as a hobby, the opportunity to become a field naturalist, making observations that in themselves are fascinating, but it affords also the prospect of collecting exciting new facts that will in time increase man's understanding of how affairs are managed in the world of nature.

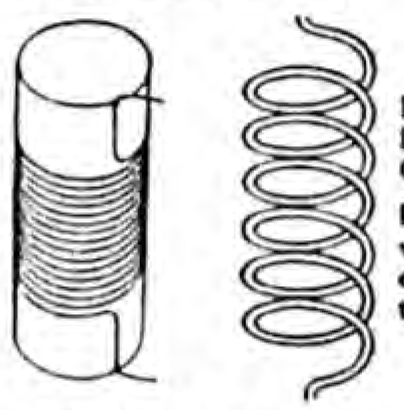
THE RADIO ENGINEER'S USE OF ELECTRICITY

This part of the study and use of electricity is often called "electronics", because the radio engineer's most important devices, thermionic valves and cathode ray tubes, make free electrons pass across a vacuum.

This is a development beyond the movement of electrons in a conductor which is explained in The Electrical Engineer's Use of Electricity, pp. 136 to 140. Of course radio engineering involves the use of conductors too. In fact the jumping-off point for radio is the behaviour of a current flowing on a coil (*see* p. 139, Electric Generators).

The Backwards Current in a Coil

LOW FREQUENCY COIL:
Many turns closely spaced of fine wire.

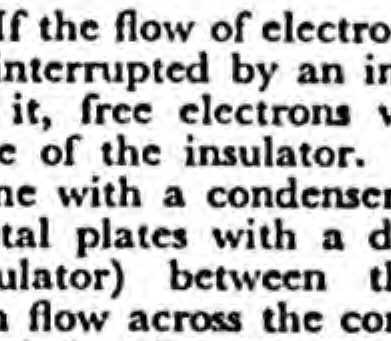


HIGH FREQUENCY COIL:
Few turns widely spaced of copper tubing.

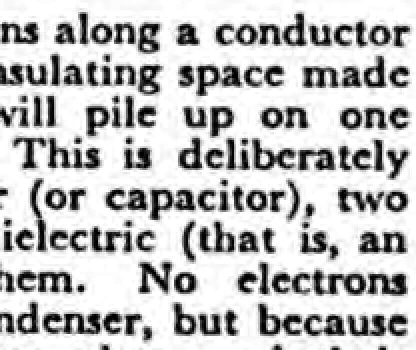
When an electric current starts to flow through a coil of wire it turns the coil into a magnet, building up lines of magnetic force. There is one odd but useful extra effect of this. As the lines of force build up along the coil their increase is like another magnet approaching the coil—and that of course tends to make current flow in the coil, but it is in the opposite direction! So the build up to the full flow of current in the original direction is delayed.

When current is switched off the magnetic lines of force in the coil collapse, and *that* induces a current the other way, i.e. the same direction as the main current, opposing the collapse and delaying the decay of the original current. This effect is called self-induction; its value can be calculated as shown on p. 204.

Condensers—Roadblocks in a Conductor



VARIABLE CONDENSER (dielectric is air) vanes turn to vary effective facing plate area (shaded).



ORDINARY CONDENSER, cutaway showing pairs of metal plates, between all of which is a dielectric.

If the flow of electrons along a conductor is interrupted by an insulating space made in it, free electrons will pile up on one side of the insulator. This is deliberately done with a condenser (or capacitor), two metal plates with a dielectric (that is, an insulator) between them. No electrons can flow across the condenser, but because of their pile-up on one plate, and their scarcity on the other, there is a potential difference between the two plates. A condenser will hold this charge for long periods. If a "short cut" round the condenser is made for the electrons they will flow along it and bring the circuit back to balance.

The mathematical calculations that are necessary for a detailed explanation and proof of what is invisibly happening in an electronic circuit are somewhat complicated. These detailed explanations have therefore been set out at the end of the main description of the principles of electronic engineering. It is worth noting that these mathematical descriptions of events happening in electronic circuits are now regularly seen as pictures traced on the cathode-ray-tube screens of oscilloscopes.

Current Going To and Fro in a Circle.

If a coil (inductance) and a condenser (capacity) are used together in a circuit which is given one short surge of electric current the net effect is that electrons from the backward current from the coil pile up on one plate of the condenser. Then, as the current from the coil ceases, the condenser discharges, sending its piled-up electrons as a current through the coil in the opposite direction. That makes another pile-up of electrons on the opposite condenser plate—and the process starts again, gradually getting weaker as the resistance of the wire takes a toll of the electrical energy.

This to-and-fro-in-a-circle process is called oscillation. Provided a fresh "kick" of current can be supplied at just the right moment to be in time with the ebb and flow of oscillatory current the circuit will maintain its oscillations indefinitely just as you can keep a swing going if someone gives it a push that helps and does not hinder it. Every circuit has a natural timing (frequency) of ebb-and-flow depending on the speed with which the magnetic field in the coil rises and collapses, and also on the time it takes the condenser to become fully charged up with all the electrons the PD makes available. That natural frequency causes the greatest amount of current to flow in each direction at each half cycle. This is called the tuned circuit's Resonant Frequency.

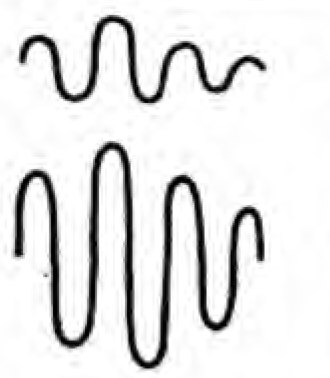
It is oscillations like this that produce electro-magnetic waves that can be broadcast from a radio or television transmitter, or a radar set. The tuning knobs of a radio set adjust a tuned circuit to select the station you want. And a tuned circuit in a receiving radio, TV, or radar set (if adjusted to have exactly the same resonant frequency as a particular transmitted frequency), will respond and oscillate in time with its greatest possible flow of current. So other frequencies coming into the tuned circuit get hardly any response at all, because they only set up oscillations that get cancelled out by the backwards current of the coil being at loggerheads with the discharge of the condenser.

Valves

People often wonder why valves are needed in a radio set. If a tuned circuit will select the right frequency signal why do we need valves as well? The answer comes in two parts:

Making Signals Grow Stronger (Amplification)

Valves have the extraordinary ability of amplifying a very weak signal (i.e. an Alternating Current that is very small in strength) into one that while exactly following its variations is very much stronger. How they do it is described on p. 203. As a result signals which have become very

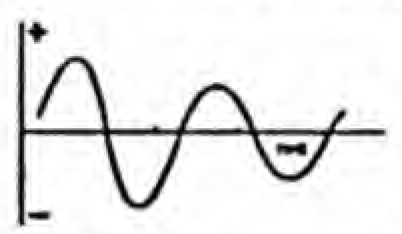


AMPLIFICATION
Top: a graph of a weak varying signal applied to the grid of a valve. Below: the current flow at the anode of the valve. It is a strong signal, following the same variations.

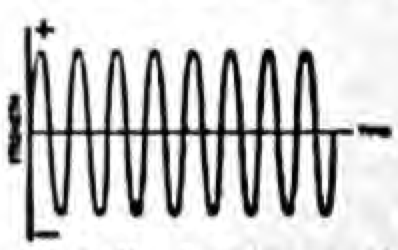
weak after travelling hundreds or even thousands of miles can be picked up and made large enough to be useful.

Picking Out the Part of the Signal You Can Hear (Detection)

The signal has to be made to vibrate a loudspeaker at speeds your ear can hear, but unfortunately it is only electro-magnetic vibrations that are much faster than that which will make a journey through space without being absorbed on the way. The signal your radio receiver is getting (the carrier) is of a frequency thousands of times greater than the frequencies you can hear.

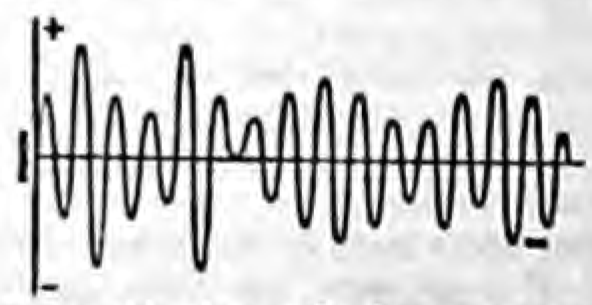


An audio frequency, one that you can hear, shown as the electrical variations of a microphone, changing in both frequency and strength.



A radio frequency—the Carrier Wave—much faster electrical variations generated in a radio transmitter. Frequency and strength do not vary.

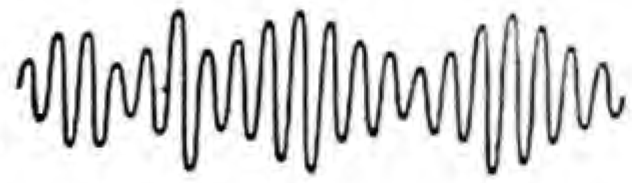
Even if the loudspeaker could be made to vibrate at this speed you would not hear it. But the signal has been sent out from the broadcast transmitter not as a level strong one, but varying from weak to strong.

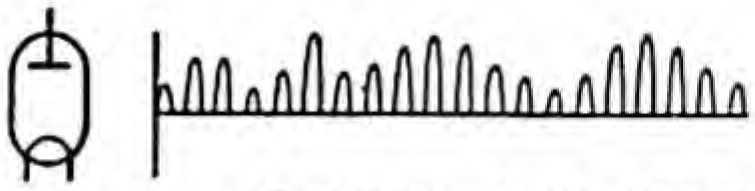


The two combined: a radio frequency varying in strength at the audio frequency of the microphone. The level carrier wave has been given a varying amplitude that changes in time with the audio frequency. This wave will travel through space.

And the speed at which this strength variation changes is in time with the frequencies of the sounds made in the broadcast studio, and turned into electrical variations by the microphone. Something has to be done about extracting the strength variations so they can be fed to the loudspeaker. What is done is to put this modulated Carrier frequency — an Alternating Current — through a non-return valve (thermionic valves, to give them their proper name, are, in fact, *valves*—electrons can only flow one way through them, from cathode to

Received by radio receiver It is "detected".

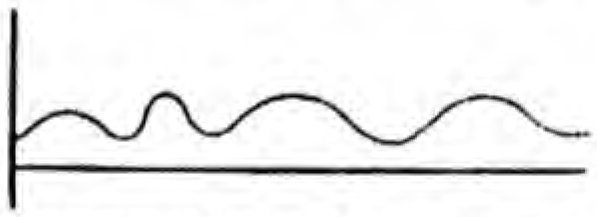




Put across anode and cathode of a diode valve, only the positive half-cycles can cause electron flow through the valve. The output current is a series of pulses like this.

anode). A valve must have a potential difference between the anode and the cathode before electrons can fly across, and the anode must be more positive than the cathode to provide the pulling power. The carrier A.C. is fed across between anode and cathode. The result is the negative halves of the cycles do not provide any pull for the electrons, so the valve does not conduct and there is no output of electrons at the anode. The positive half cycles make the anode positive to the cathode and the valve conducts. As output there is left a series of spurts of current, all positive, a reproduction of only the positive half cycles of the carrier. But a line drawn (as a graph), connecting the peaks of the spurts

Dotted line connecting peaks of pulses.



The effect of the pulses of detected radio frequency is the same as a D.C. voltage varying in strength at the audio frequency. This will work a loudspeaker.

forms a gradual curve that goes up and down at the rate of sound waves. And this will make a loudspeaker work audibly. This is all called Detection.

The peaks of the detected R.F. make the A.F. that works the loudspeaker.

Valves in a Transmitter

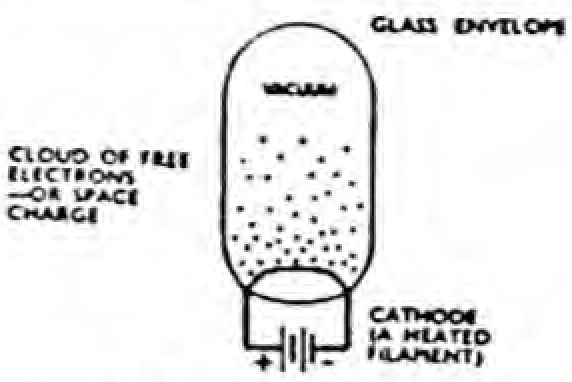
The basic part of a radio transmitter is the circuit which produces the oscillation at the required frequency for the carrier-wave. These circuits include a valve because, as was mentioned earlier, if an oscillation is to continue it must receive a "kick" to help it on every swing, and valves can amplify the swing and feed part of the amplified signal back to the oscillatory circuit as the necessary "kick" (*see* Oscillatory Circuits). Eventually audio frequency variations are superimposed on the carrier frequency oscillations, usually by means of an extra grid in one of the valves (*see* Thermionic Valves).

Radio Waves

Radio waves, are given off when electro-magnetic fields rise and collapse continuously. Think of the field in a coil and imagine that some of the outer lines of force got left behind as the field collapsed, and formed themselves into complete loops. As all radio waves travel at the same speed (186,000 miles per second, like light), if there are, say, 93,000 oscillations per second, then the first electro-magnetic wave will have travelled 2 miles by the time the second one starts.

THE THERMIONIC VALVE

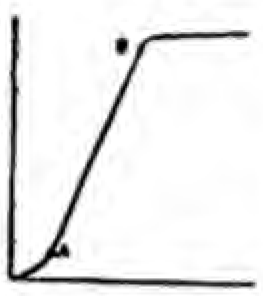
Any metal, when heated to a high enough temperature, will give off electrons from its surface. This effect called "Thermionic emission" is found to be much increased if the metal is coated with certain other substances, such as the oxides of barium, strontium or thorium. The electron emission can be explained in terms of the

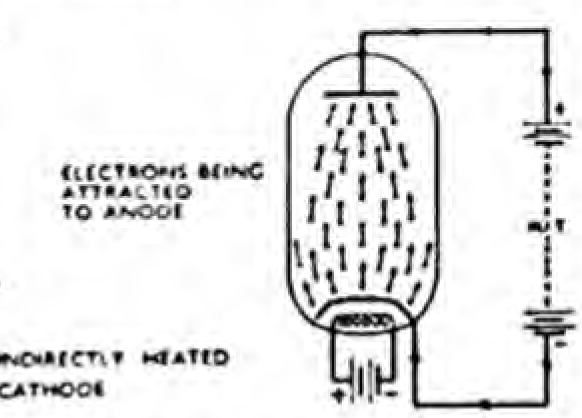


free electrons that are responsible for conducting the electric current (*see page* 136). As the temperature rises their energies increase until some of them are able to leave the metal surface, in much the same way as molecules evaporate from the surface of a liquid.

In the thermionic valve the metal emitting electrons takes the form of a filament enclosed in a vacuum, and heated by an electric current. As long as the heat is maintained the electrons just wander about freely around the filament in a "cloud" which is known as the "space charge".

Electrons are attracted from this cloud right away from the original conductor (called the Cathode) by putting a metal plate (called the Anode) inside the vacuum, and establishing a potential difference between Anode and Cathode where the anode is positive to the cathode. There is a steady flow of electrons across the valve.

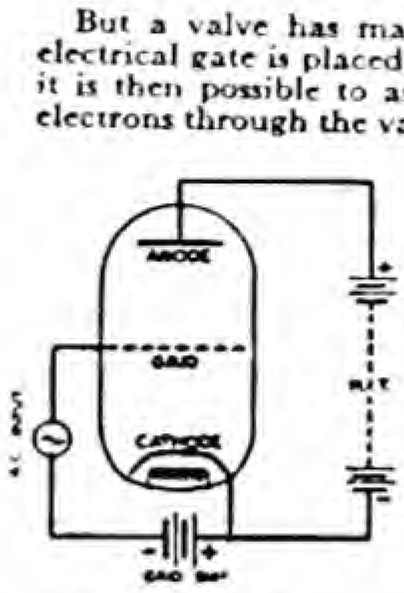




At low anode voltages the repelling action of the space charge tends to drive electrons back into the cathode. This prevents a proportional increase in anode current for an increase in voltage. Once that repelling action is overcome by a certain voltage (A on the graph) then the current flow (vertical line of graph) rises rapidly in proportion with the rise in voltage (horizontal line), until point B is reached. Any increase beyond point B would serve no useful purpose. It is termed saturation point, or the point where high anode voltage is drawing the electrons to the anode as fast as they are liberated from the cathode. The useful function of the valve lies between points A and B and is known as its "Characteristic".

This is the simplest type of valve, the Diode.

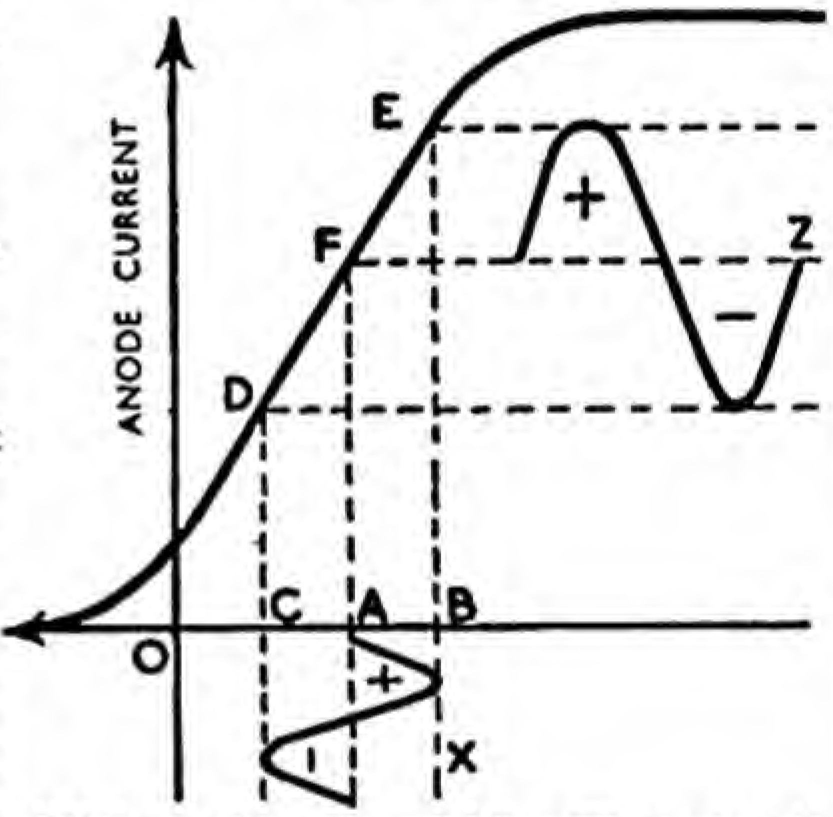
But a valve has many more uses if a sort of electrical gate is placed in the electron stream, for it is then possible to assist or oppose the flow of electrons through the valve, controlling the flow to



TRIODE VALVE: it has a grid between anode and cathode, which acts as an electrical "gate". The circle on the left with the wavy line in it is the conventional symbol for an alternating voltage, here applied between grid and cathode.

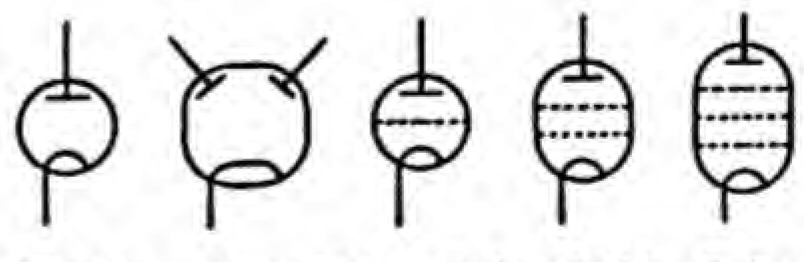
reproduce as a big varying flow out at the anode the small varying input voltage put onto the electrical gate. This "gate" takes the form of a minute wire-netting fence between the anode and cathode, known as a "grid".

A steady H.T. D.C. voltage applied between anode and cathode, causes a steady electron flow as in the diode. In the graph this is represented by A.F.Z. (No. A.C. signal applied.) A steady voltage OA is applied to the grid (grid bias). If an A.C. voltage is supplied to the grid the + ve half wave will increase the grid volts which will now be higher and equal to OB. The − ve half wave reduces the effective grid voltage back to OC. When grid voltage is made OB anode current increases to BE and when grid voltage is

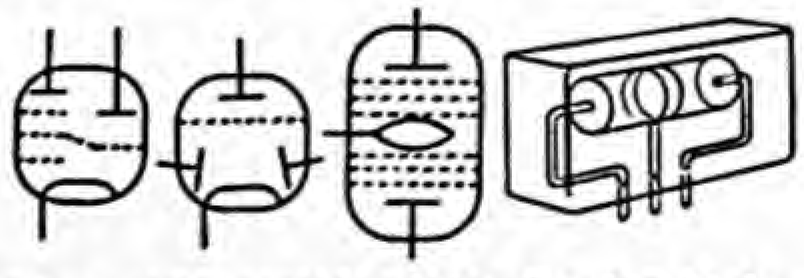


OC the anode current will fall to CD. As the grid potential swings between OB and OC the anode current swings between BE and CD. A small jump of grid voltage from C to B causes a big jump of anode current from D to E, and the steeper the curve the more pronounced this will be. Thus the valve has amplified the variations applied to the grid. In went a small varying A.C. voltage, out comes a big D.C. current varied at the same rate.

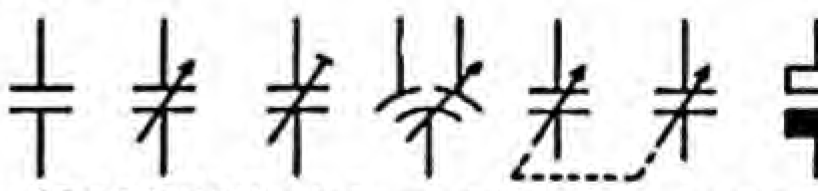
CIRCUIT SYMBOLS



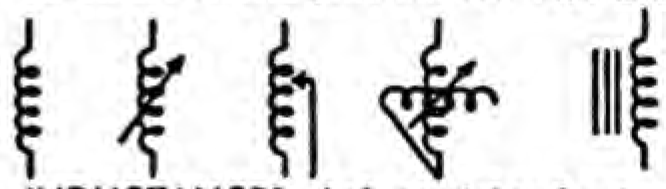
VALVES. Left to right: diode; double diode: triode; tetrode; pentode.



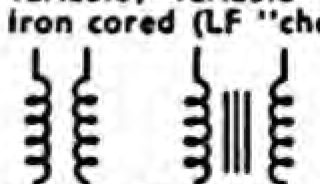
Left to right: pentode triode mixer (e.g. for frequency changing). Double diode and triode. Push-pull pentode (e.g. for AF output). Sketch of arrangement of electrodes of transistor, see p. 205.



CONDENSERS. Left to right: fixed; variable; semi-fixed; differential; two condensers ganged together; electrolytic, for use with D.C. only.



INDUCTANCES. Left to right: fixed, air cored; variable; variable (tapped); variometer; fixed, iron cored (LF "choke").



TRANSFORMERS. Left: air cored. Right: iron cored.

RESISTANCES. Left: fixed. Right potentiometer

INDUCTANCE OF A COIL

Inductances are known by the symbol L and are measured in a unit called the Henry (H), though because the value of 1 henry is very large, in radio work micro-henries are used as the unit (i.e. one millionth of 1 henry, μH). To a flow of alternating current (one that flows first in one direction, building up to a peak, then dying down, stopping and building up in the reverse direction like this ~) an Inductance offers a "resistance" depending on the frequency of the AC cycle (symbol f) and the value of the inductance in henries (L).

$X_L = 2\pi fL$ (the answer is in ohms Ω).

X_L is the symbol for inductive reactance to distinguish this sort of "resistance" to current flow from ordinary Resistance (R) in a straight wire. But X_L is measured in ohms just the same.

Example 1: What is X_L of a ·005H coil at a frequency of 5 Kc/s. (5,000 cycles per second) and at 50 c/s. A.C.?

$X_L = 2\pi fL = 6{\cdot}28 \times 5{,}000 \times {\cdot}005 = 157$ ohms.

$X_L = 2\pi fL = 6{\cdot}28 \times 50 \times {\cdot}005 = 1{\cdot}57$ ohms.

Example 2: A current of 2 amps is passing through a coil of ·005H at 50 c/s. and again at 5 Kc/s. What is the applied voltage in each case?

$E = IR$ *or* $2\pi fL \times I = 6{\cdot}28 \times 50 \times {\cdot}005 \times 2 = 3{\cdot}14$ volts.

$E = IR$ *or* $2\pi fL \times I = 6{\cdot}28 \times {\cdot}005 \times 5{,}000 \times 2 = 314$ volts.

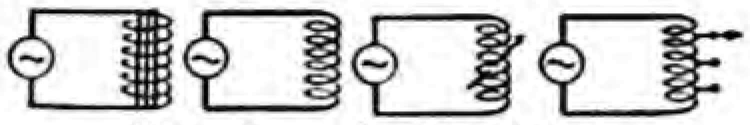
Example 3: What is the value of I through a ·005H coil if 500 volts A.C. at 50 c/s. and again at 5 Kc/s. are applied?

$$I = \frac{E}{R} \text{ or } \frac{E}{2\pi fL} = \frac{500}{6{\cdot}28 \times 50 \times {\cdot}005}$$

$= 318{\cdot}5$ amps approx.

$$I = \frac{E}{2\pi fL} = \frac{500}{6{\cdot}28 \times 5{,}000 \times {\cdot}005} = 3{\cdot}185 \text{ amps approx.}$$

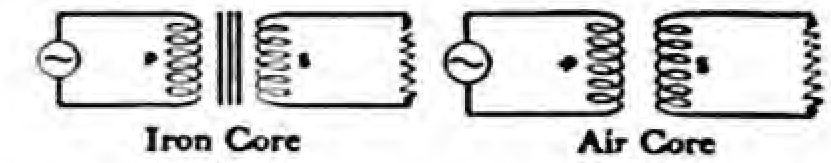
If the value of L is increased the frequency f for a fixed value of I will be decreased and if f is increased the value of I is decreased.



Illustrations of a few chokes.

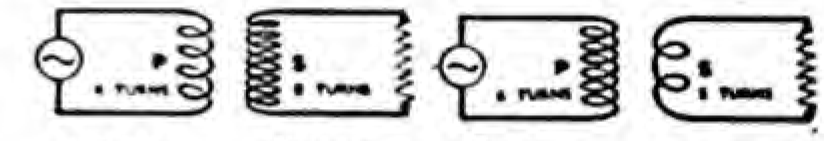
(a) L.F. Choke (b) H.F. Choke (c) Variable Inductor (d) Inductor with variable tapping.

Inductors in Series and Parallel are calculated in exactly the same way as resistors provided that their fluxes do not overlap.



Iron Core (a) L.F. or Mains Transformer — Air Core (b) H.F Transformer

Transformers are mutual inductors in which lines of force from the primary coil embrace the secondary coil. PD is produced in the secondary coil but current flow will be in the opposite direction at each half cycle of A.C. to that in the primary. Transformers are designed in particular ratios between primary and secondary coils to step voltages and currents up or down as required.



4 turns 8 turns 6 turns 2 turns

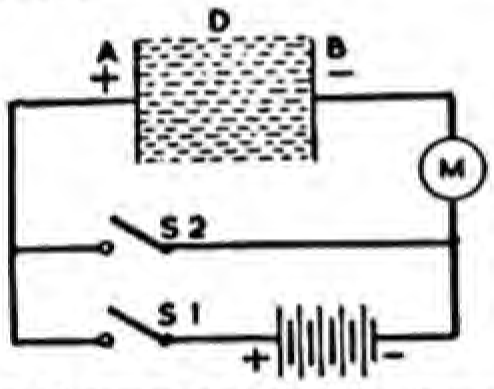
(a) 2 : 1 Ratio Step up — Primary 240V: Secondary 480V

(b) 1 : 3 Ratio Step down — Primary 240V: Secondary 80V

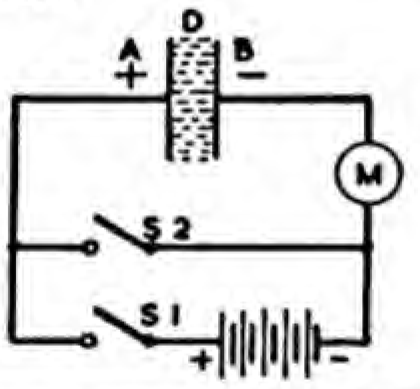
CAPACITY OF A CONDENSER

Capacitances (or condensers) are known by the symbol C and are measured in a unit called the Farad (F), though because the value of 1 Farad is too large for electronic circuits, microfarads (μF, millionths, and micro-microfarads, $\mu\mu$F, millionths of millionths) are used as practical units.

A condenser is two pieces of metal side by side but insulated from each other by some "dielectric" (non-conductor) D, such as air, mica, glass, waxed paper, etc., so that the condenser forms a gap in a circuit, as below.



If S1 is closed completing the circuit except for the gap the condenser forms there will be a momentary rush of electrons from Plate A via the battery to Plate B; this will make A positively charged and B negatively charged, causing a state of stress across the dielectric D like the compression of a spring. The charge will continue to build up on the plates until the PD equals that of the battery.

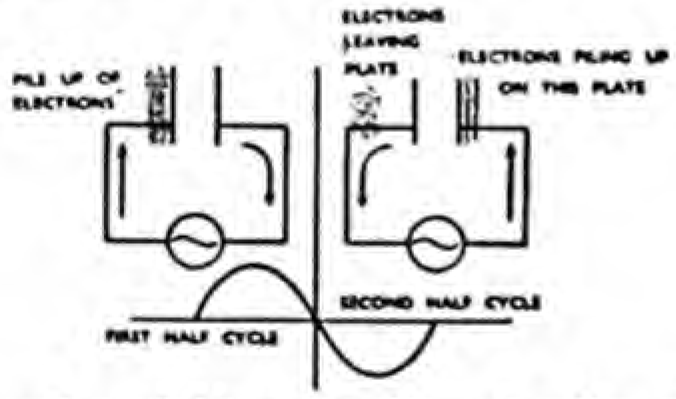


If the plates are moved closer together the meter M (a sensitive voltmeter) would indicate a further movement of electrons from A to B, causing greater stress in D. This flow would continue until the PD on A and B once more equalled that of the battery. The closer the plates of a condenser are together the greater the charge it will take. A good condenser should hold its charge for a considerable period.

With S1 still open, if S2 were closed—completing a short cut for the electrons—a spark would be seen at S2. There would now be a momentary rush of electrons from B to A via S2, bringing both plates of the condenser back to balance.

If S1 is closed again and the condenser is charged up again, S1 is then opened and S2 closed again, M will show another deflection indicating a return flow of electrons from B to A via S2.

If a flow of Alternating Current (instead of Direct Current) was applied across the circuit when S1 was closed it would not be necessary to have the short cut S2. For electrons building up on one plate during one half cycle of current flow in one direction would join the flow in the *opposite* direction during the next half cycle. The pile-up of electrons would be first on one plate, then on the other.



To a flow of Alternating Current a Capacitance offers a "resistance" (called capacitive reactance) depending on the frequency of the A.C. cycle and the value of the condenser in farads.

$$X_C = \frac{1}{2\pi fC} \quad (X_C \text{ is in ohms } \Omega).$$

Example 1: What is the Xc of a condenser of 2μF when an A.C. voltage at 50 c/s. and 5 Kc/s. is applied?

$$X_C = \frac{1}{2\pi fC} = \frac{1}{6{\cdot}28 \times 50 \times {\cdot}000002} = \frac{1{,}000{,}000}{6{\cdot}28 \times 100}$$

$$= \frac{10{,}000}{6{\cdot}28} = 1{,}592 \text{ ohms approx.}$$

$$= \frac{1}{2\pi fC} = \frac{1}{6{\cdot}28 \times 5{,}000 \times {\cdot}000002}$$

$$= \frac{1{,}000{,}000}{6{\cdot}28 \times 10{,}000} = \frac{100}{6{\cdot}28} = 15{\cdot}92 \text{ ohms approx.}$$

Example 2: What is the current charging a condenser of 2μF when a voltage of 400 at 50 c/s. and 5 Kc/s. is applied?

$$I = \frac{E}{X_C} \text{ (at 50 c/s. 1,592 } \Omega\text{, see above)} = \frac{400}{1{,}592}$$

$= {\cdot}251$ amps approx.

$$I \times \frac{E}{X_C} = \frac{400}{15{\cdot}92} = 25{\cdot}1 \text{ amps approx.}$$

It will be seen from this that Xc is high when f is low and low when f is high; also that I increases as f increases.

Calculations for capacitors in series and parallel are worked out in the same way as Resistances and Inductances except that capacitors in Series are calculated like Resistances in Parallel

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \text{ and so on.}$$

The total value as with resistances in parallel must be less than the lowest value of any of them.

Capacitors in Parallel are treated the same as Resistances in Series

$C = C_1 + C_2 + C_3$.

This will be obvious because the plate area has been increased and not reduced, as is the case in series.

IMPEDANCE IN A TUNED CIRCUIT

A circuit made up of a combination of a coil and a condenser (or several of each) is called a tuned circuit because the combined effect of the Induced E.M.F. of the coil and the discharge of the condenser, when an alternating current is applied across the circuit, is to encourage the to-and-fro flow of electrons. This is called an Oscillatory Circuit (current flow oscillates first one way and then the other). The time factor of the two effects (L and C) acting partly in opposition to one another is obviously important.

Inductance of a coil increases with greater frequency, but capacitance of a condenser decreases with greater frequency.

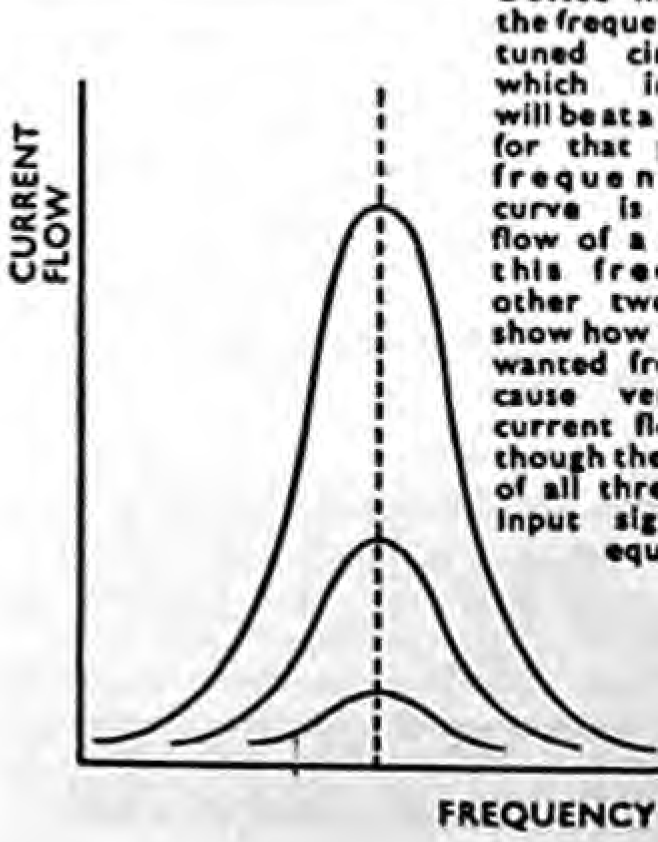
$$X_L = 2\pi fL \text{ and } X_C = \frac{1}{2\pi fC}$$

So a combination reactance will be the difference between the two: $= (X_L - X_C)$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \text{ (obtained by vector addition)}$$

Z is the total impedance offered by a circuit. R is the ordinary resistance of the wires in the circuit.

At one particular frequency the coil and the condenser will offer the same impedance to the A.C. voltage, and the greatest flow of current is allowed by the oscillatory circuit. This frequency will be



Dotted line marks the frequency of the tuned circuit, at which impedance will be at a minimum for that particular frequency. Top curve is current flow of a signal at this frequency, other two curves show how other unwanted frequencies cause very little current flow, even though the strength of all three in the input signal was equal.

$$f = \frac{1}{2\pi\sqrt{LC}}$$

L is in Henries, C is in Farads and f in cycles per second.

It is the same whether the coil and condenser are in series or parallel.

For a particular frequency to be picked out from many frequencies by a tuned circuit it is only necessary to adjust the values of L and C so that the combined impedance Z is least for that frequency, and the current flow in the tuned circuit will be maximum in time with the chosen frequency.

HENRY. The unit of measurement of inductance. When a PD of one volt is induced, and current changes at 1 ampere per second, the inductance of a coil is 1 henry.

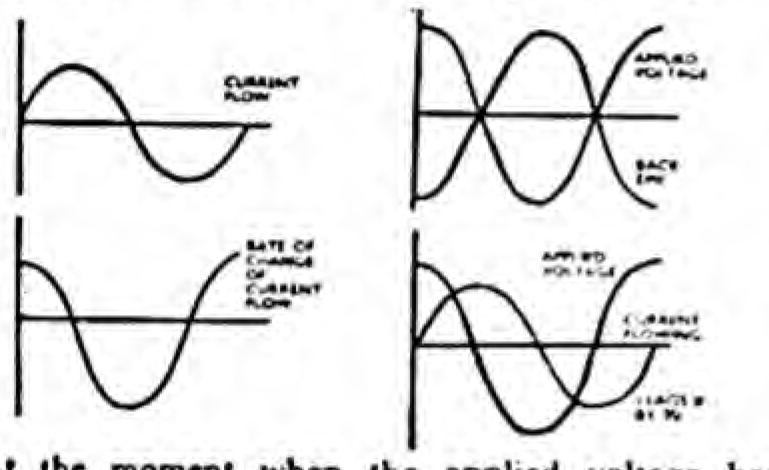
FARAD. The unit of measurement of capacitance. When a charge of 1 coulomb raises the PD across a condenser by 1 volt, the capacitance of the condenser is 1 farad.

Current "Lag" & "Lead"

THE EFFECT OF INDUCTIVE REACTANCE ON ALTERNATING CURRENT FLOW IN A COIL

A positive surge of alternating current flowing through a coil builds up a magnetic field, which induces a *backward* pressure (known as "back E.M.F.") in the coil, in the opposite direction to the current caused by the applied voltage. As this opposition builds up, of course, it means that the rise in current flow to match the rise in the applied voltage gets delayed. It is rather like the applied voltage being faced with an increasing resistance, less current flows than would flow for the same voltage in a straight wire.

Now the cause of the "back E.M.F." is that as the current produced by the applied voltage increases from moment to moment it creates an increasing number of lines of force through the coil. The increase in lines of force is equivalent to the N pole of a magnet being brought quickly towards the S pole of the coil. The direction of current induced by the approach of this imaginary magnet must be such as to stop the change that caused it. That means a flow of current in the coil in a reverse direction to turn its S pole into an N pole and so repel the "magnet".

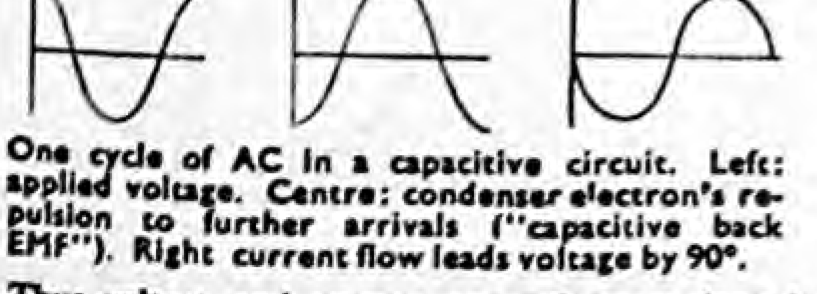


At the moment when the applied voltage has reached its positive peak the current starting from zero will be *increasing* at its greatest rate (from 0 to 1 is a faster rate of increase than from 9 to 10) so the back E.M.F. will be at its peak value. It tends to cancel out some part of the applied E.M.F. When the applied voltage starts to diminish the rate of *increase* of the current begins to get easier, so the back E.M.F. diminishes as the lines of force begin to collapse. In collapsing they produce a current flow which tries to prevent their collapse. This must, of course, be in the same direction as the original current. So total forward flow of current *continues to build up while the applied voltage is going down.* When the applied voltage has fallen to zero the forward flow of current is sustained only by the collapse of the magnetic field. The two sequences are 90° apart since applied voltage starts at maximum and current at zero. (Current obviously lags 90° behind voltage, because ¼ of a cycle (360°) = 90°.)

Note: The above is only true for an operating condition, the *starting up* process would not show a 90° lag, because this lag is largely due to a carrying over effect from the *previous* quarter phase. On *starting up* current will more nearly follow voltage (as per Ohms Law) with only a minimum amount of lag due to back E.M.F.

THE EFFECT OF CAPACITATIVE REACTANCE ON ALTERNATING CURRENT FLOW IN A CONDENSER CIRCUIT

By the time the applied voltage has reached its + ve peak, current flow into the condenser has ceased, because the electrons which the applied E.M.F. forced into the condenser have developed a maximum repulsion (equal to the applied E.M.F.) against any further arrivals. As the applied E.M.F. starts to fall current *starts* to flow in the opposite direction under this influence of repulsion (i.e. a capacitative back E.M.F.). It does not at once reach its maximum value since there is still an applied but declining forward E.M.F. When this applied E.M.F. has fallen to zero the current flowing to the other plate of the condenser is maximum. It then begins to diminish *although* the applied E.M.F. is now working in the same sense, since the condenser plates are now becoming charged up and developing back E.M.F. Current becomes zero again when the applied E.M.F. has reached its − ve maximum i.e. completion of ½ cycle).

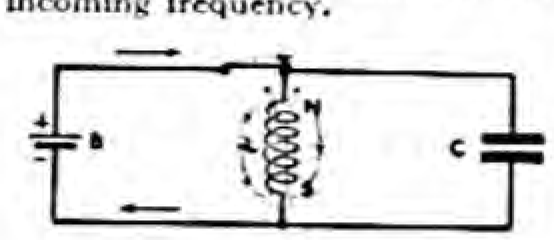


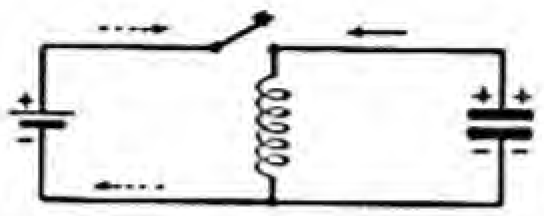
One cycle of AC in a capacitive circuit. Left: applied voltage. Centre: condenser electron's repulsion to further arrivals ("capacitive back EMF"). Right current flow leads voltage by 90°.

Thus voltage and current are 90° apart (one is maximum when the other is minimum—a quarter cycle difference = 90°) and current is seen to lead voltage.

OSCILLATORY CIRCUITS

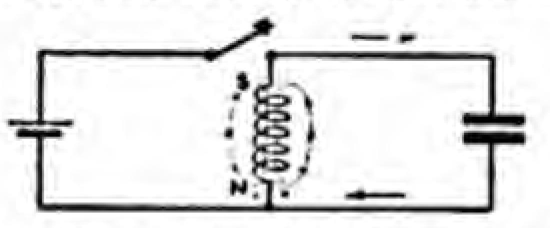
Sometimes radio engineers wish to *start* an oscillation at a particular frequency. Mostly this is for creating the carrier wave for a transmitter, or the mixing frequency used in a superhet receiver to "beat" with the incoming frequency.



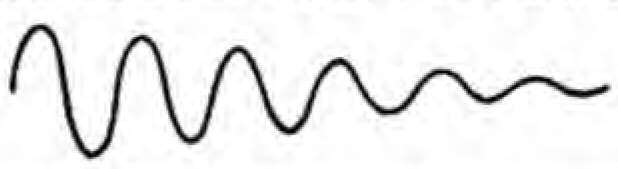


Simple Oscillator

If the switch is closed completing the battery circuit B, a current will flow through the coil producing a magnetic field around the coil as shown in (1). At the instant of *opening* the switch the magnetic field starts to collapse. While the field is in the process of collapsing it tends to maintain through L a current in the same direction as that which has just been cut off. This current flows into condenser C which becomes charged as shown in (2); (the magnetic lines are absent, representing a moment when the current ceases to flow). The whole of the energy having now been transferred to C (displaced electrons) L and C cannot stay in this unbalanced condition so C will now discharge (3) through L causing a current to flow through it in the opposite direction to the current originally supplied by the battery. A field is again built up around L, but this time with its polarity (N and S) reversed as shown in (3). This field will again collapse and charge C again, but in the opposite polarity to that shown in (2).

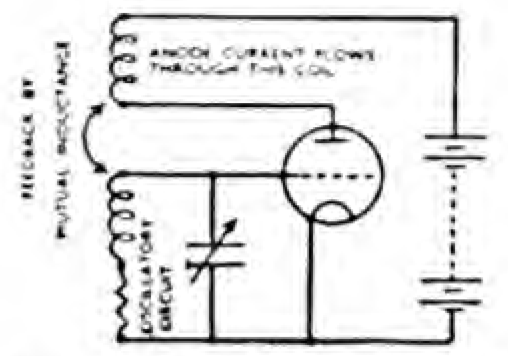


This process of oscillation from L to C and C to L would go on indefinitely if the circuit did not contain resistance, which it does, in the form of connecting wires and the resistance of L and C themselves, so the oscillations will die down after a short time like this:



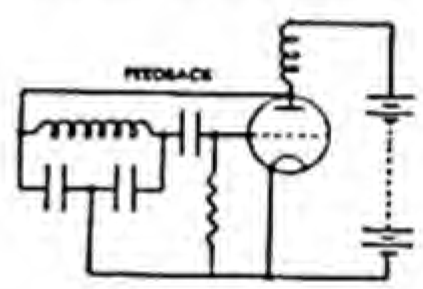
But if we close and open the switch for a moment, in time with the oscillations, then the process would continue as long as we continued to supply energy to the circuit. The amount of energy needed to keep the oscillations going indefinitely would be very small, only just enough to overcome the resistance of the circuit.

All that is required of course is the "kick" fed in at just the right moment to the tuned circuit. As it is not available from outside it must come from the circuit itself, and it does—for instance, in this way:

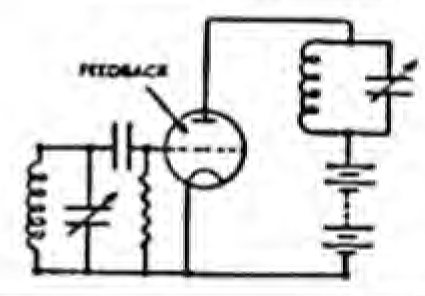


The tuned circuit is connected across the grid and cathode of a valve. The valve amplifies the resonant frequency of the tuned circuit, which appears as an oscillating anode current. This anode current passes through another coil near the coil of the oscillating circuit setting up magnetic lines of force which affect coil No. 1 by mutual inductance, setting up current flow in it—a "kick" is being fed back to the oscillatory circuit, so it maintains its oscillations.

Care has to be taken to see that the currents induced by the feed-back are in phase (i.e. + ve when it is + ve) with the oscillatory current or the oscillations will be damped down. The *timing* of the feed-back is bound to be correct for it is determined by the oscillations fed into the grid of the valve. Two more valve oscillator circuits:

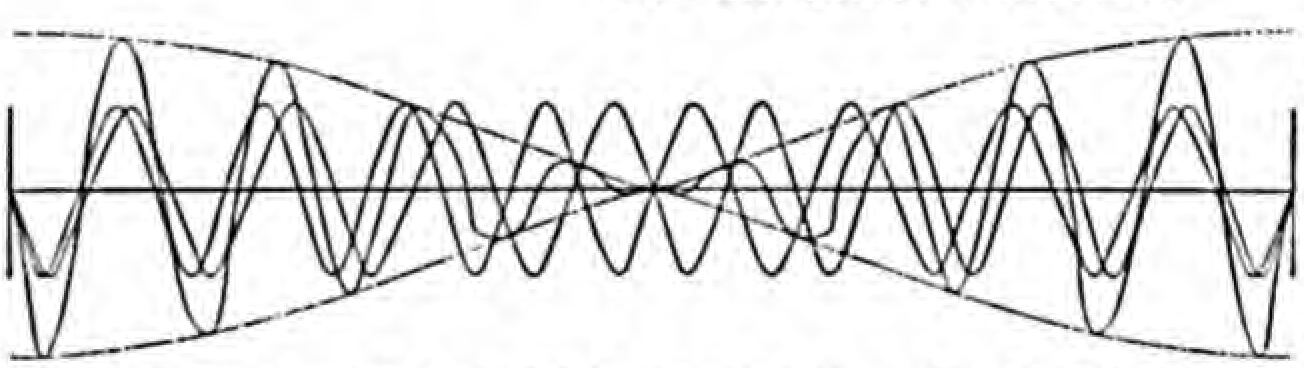


Colpitts oscillator.



Tuned-anode-tuned-grid oscillator Feed-back through capacitance between anode and grid.

THE SUPERHET PRINCIPLE



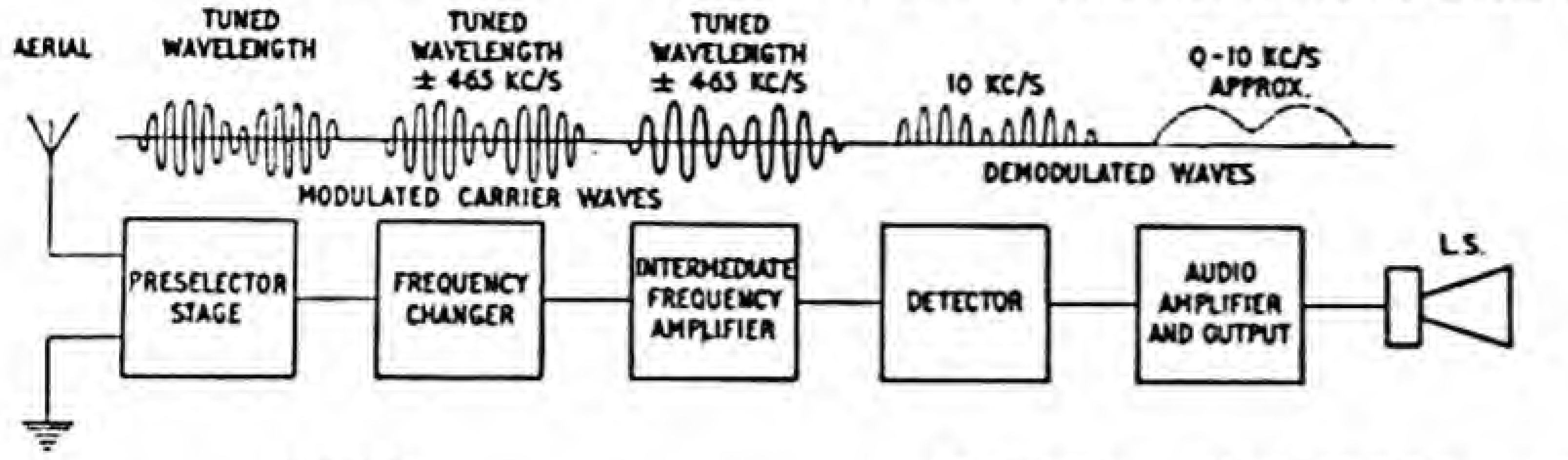
Graph of two different frequencies of the same amplitude, and their mean value at every point—i.e. the "beat" frequency. 9 and 8 beat as 1, that is they add up to a third frequency whose amplitude variations themselves follow a shape—dotted line—that is one cycle per period (9—8=1).

More than one valve is needed in a receiver to amplify high-frequency signals from very distant transmission stations, but it is rather a nuisance to keep all the circuits of these valves tuned to the selected frequency—the tuning of one may easily go off and then no signal would get through to be detected. So all incoming frequencies are reduced to one set intermediate frequency in superhet (or, more formally, "supersonic heterodyne") receivers. The receiver generates an oscillation at a frequency which is (usually) 465 Kc/s. different from (above or below) the selected radio frequency. The oscillator is tuned *in step with* the input radio frequency tuned circuit. Then the modulated radio frequency and the unmodulated oscillation are fed into two adjacent grids in one valve, so that they both affect the electron flow through the valve. The result is, as can be worked out as a graph, the two tend to cancel each other out—but not exactly. They "beat" together and the output is a frequency of the *difference* between the two—the Intermediate Frequency (IF), varying in strength (amplitude) as the radio signal was. This modulated IF is amplified and then detected. Usually the whole process takes place inside one specially designed valve, a frequency changer. This has a triode at one end, to the electrodes of which the oscillatory circuit is connected; and an amplifying pentode at the other, into which the radio signal is fed on one grid. The grid of the triode is connected to a different grid of the pentode, so feeding the oscillation into the electron flow already varied by the radio signal.

TRANSISTORS

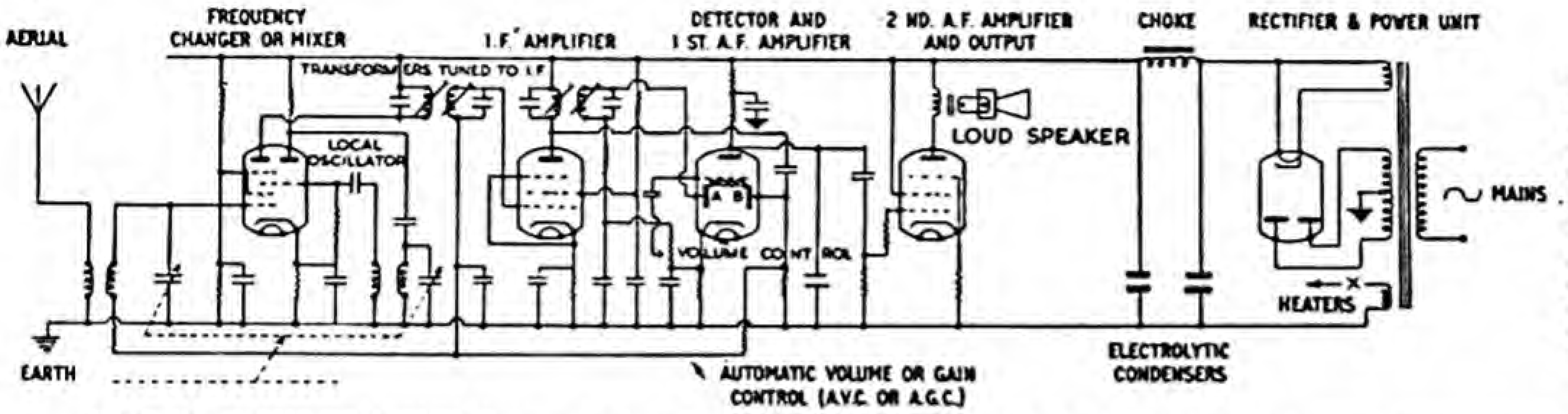
These convenient substitutes for thermionic valves consist simply of a piece of ore of the "semi-conductors", with an electrode (anode and cathode) at each end to hold it; a third electrode consists of a loop of wire wrapped round the centre of the semi-conductor—this is the grid. The most useful semi-conductors are silicon and germanium, either of which with a very minute quantity of some other suitable substance acquires an unusual state of electronic balance which is not yet fully understood. In the form of a transistor it then: (1) offers a varying resistance to voltages across it according to the "grid" voltage (i.e. amplifies); (2) oscillates to a fixed frequency like a piezo-electric crystal, though the transistor's frequency is determined by point of contact of electrodes (i.e. the transistor acts as a valve oscillator); and (3) allows current flow only in one direction (i.e. detects an A.C. signal).

CIRCUIT DIAGRAM SHOWING STAGES OF A SUPERHET RADIO RECEIVER, WITH GRAPHS OF SIGNAL AT EACH STAGE.



DETECTOR DIODE A: chops off bottom half of IF waves. Part of its output is tapped by volume control variable resistance and put onto grid of AF amplifying (triode) part of same valve.

DETECTOR DIODE B: also detects IF signal, but uses its output as negative bias on earlier valves to reduce their output when signal is too loud. This is Automatic Volume Control.



RECTIFIER: each anode of a double diode being connected with opposite end of power transformer (centre point is earthed) each will conduct one half of the AC mains cycle, turning the ∿ shaped cycle into ⌒ two humps as output from the two anodes. The choke and electrolytic condensers smooth this hump-back effect into an appromimately level DC voltage.

GANGED TUNING CONDENSERS shown by dotted lines connecting their "variable arrows". These are for selection of frequency required, and for keeping superhet oscillator in step, (but *different*—above or below—by the beat or Intermediate Frequency). The wavebands, long, medium or short are preselected by switching in or out extra condensers (not shown here) in the tuning circuits, so altering their overall range of frequency.

RADAR

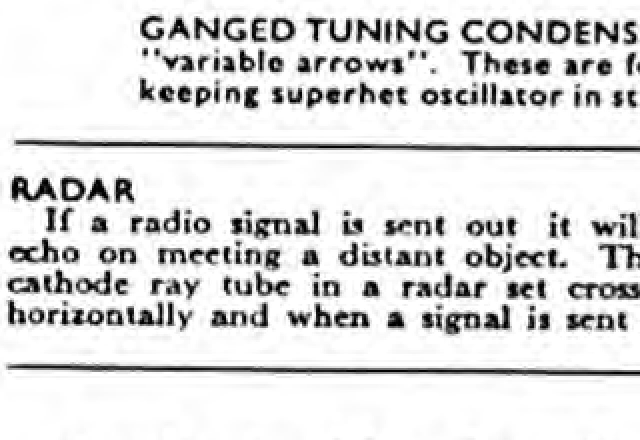
If a radio signal is sent out it will produce an echo on meeting a distant object. The beam in a cathode ray tube in a radar set crosses the screen horizontally and when a signal is sent out a bright spot appears. Another bright spot appears when the echo returns. The distance of the object from which the radio waves have been "bounced back" is shown by the distance between the two pin-points of bright light.

A directional aerial records the position of objects in its path in the corresponding quarter of a circle on the radar screen. Fluorescent material keeps the bright spot glowing long enough to give a continuous picture.

THE PATHS OF RADIO WAVES

A radio signal broadcast from an aerial near the surface of the earth spreads outwards in growing hemispheres, gradually getting weaker the further it goes. Owing to the curve of the earth it will not directly reach to any great distance. This is called the ground wave. But fortunately there exists, beginning at some 50 miles above the Earth's surface, an ionised region of the atmosphere (the Ionosphere) which reflects electro-magnetic radiations back to earth, so they bounce round between the earth and the Ionosphere. The greater the number of bounces the more quickly the signal loses its strength. For radio frequency (R.F.) transmission the atmosphere has

The Ionosphere: Appleton layer F, Heaviside layer E.



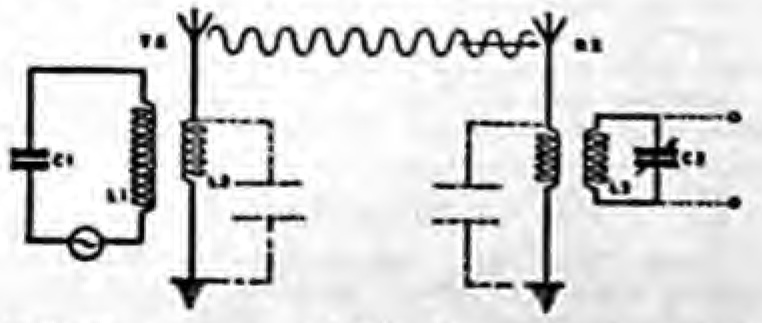
The daytime range which reached only between 1 and 2 is extended to become 1 to 4 at night. "Freak" reception is caused by unusual conditions which allow reflection as shown in 5.

two important regions, one at 60 to 80 miles up called the "Heaviside" or "E" layer, and the other at 140 to 300 miles up called the "Appleton" or "F" layer, so called after men who discovered them. Both layers are formed by the action of the sun on the gases which form the earth's outer atmosphere. The degree of ionisation of each part of the Ionosphere varies with the daily rotation of the earth itself and the varied effects of the sun during the seasons of the year. A particular frequency may be bounced back to the earth's surface at quite a different angle at one time than another. This accounts for the fact that transmission and reception is better at certain times of the day and certain seasons of the year.

Some very high-frequency waves, such as TV frequencies, go right through the Ionosphere and do not get bounced back. Their effective range is reduced to their ground wave, which usually means it is only the distance they can travel in a straight line before being blocked by a high hill, or a tall building. Even where there are no obstacles the range of the ground wave is limited by the curvature of the earth. TV transmitters are built at frequent intervals on the top of hills and mounted on tall masts to get over the difficulty.

AERIALS

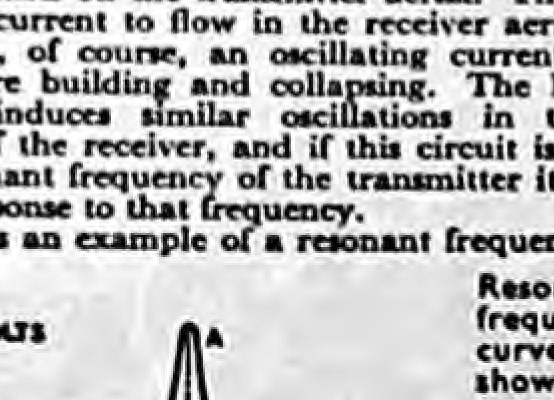
A transmitter produces oscillations in its aerial circuit which in turn give rise to electro-magnetic waves, and those waves produce similar oscillations in a receiver aerial. An aerial is a tuned circuit. The aerial itself can be called an inductance, because it is a conductor carrying an electric current, and every conductor carrying an electric current produces a magnetic field around itself. Because the aerial has air between it and the ground it must have a big capacitance in parallel with its inductance.



Oscillations generated by the transmitter induce oscillations of the same frequency in the aerial/earth "tuned circuit", from which they travel as electro-magnetic radiations to the receiver aerial/earth "tuned circuit", inducing through the transformer maximum oscillations of the transmitted frequency in the input circuit because that circuit is tuned to offer least impedance to that frequency.

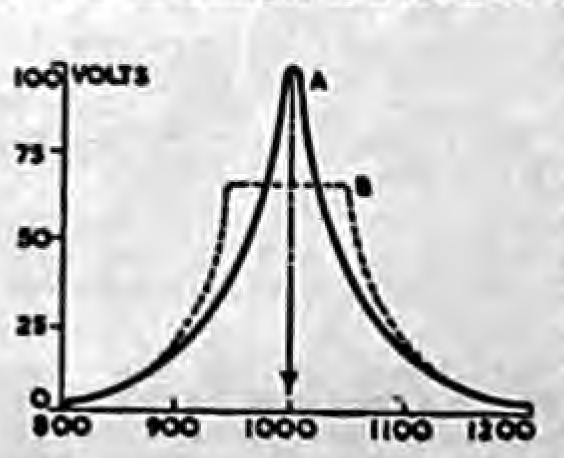
Now recalling how electricity is produced in a conductor it will be remembered that it does not matter whether we pass the conductor through a magnetic field or the magnetic field past the conductor. The result is the same—a current will flow.

The transmitter aerial is a conductor with an A.C. current passing through it, causing a magnetic field to build and collapse continually. It is radiating



electro-magnetic waves. When they reach the receiver aerial they produce magnetic whirls in it corresponding to the whirls on the transmitter aerial. These whirls cause a current to flow in the receiver aerial system which is, of course, an oscillating current, for the whirls are building and collapsing. The RF transformer induces similar oscillations in the input circuit of the receiver, and if this circuit is tuned to the resonant frequency of the transmitter it will give peak response to that frequency.

Here is an example of a resonant frequency curve.



Resonant frequency curve, showing output in volts for a fixed small input voltage. Maximum output at the 1,000 kc/s resonant frequency.

The carrier is 1,000 Kc/s. For a very small imput voltage of about 1 or 2 volts in a series-tuned circuit the magnification would be about 100 at resonance or the frequency at which $X_L = X_C$. (*See also* Impedance of a Tuned Circuit.)

It can be seen from the curve A that the circuit when tuned to 1,000 Kc/s., is highly responsive to that frequency alone and not to any other. In actual practice something like the curve B is used with a "Side band" of plus or minus a few Kc/s. to cover the overall tuning of a receiver and make its selectivity reasonably able to receive all signals of high and low AF amplitude as picked up by the aerial (i.e. high- and low-pitched musical notes, etc.). The formula or "Resonant Frequency" is $f = \frac{1}{2\pi \sqrt{LC}}$ where L is in Henrys, C in Farads and f in cycles per second;

or $f = \frac{1,000,000}{6 \cdot 28 \sqrt{LC}}$ where L is in μH, C in $\mu\mu$F and f in Kc/s.

WAVELENGTHS

The speed at which electro-magnetic waves travel is the same as for light, approximately 186,000 miles per second. In radio work this speed is always measured in metres per second and is exactly 300,000,000 metres per second.

If electro-magnetic waves are radiated from an aerial for instance a million times in one second (the output circuit of the transmitter is tuned to a frequency of 1 megacycle, 1,000,000 cycles per second) the second wave will follow the first after one millionth of a second, and in that time the first wave will have travelled 300 metres. In other words the peaks of the waves will be spaced at 300-metre intervals as they travel—the wavelength is 300 metres.

$$\lambda = \frac{V}{f} \text{ or } f = \frac{V}{\lambda}$$

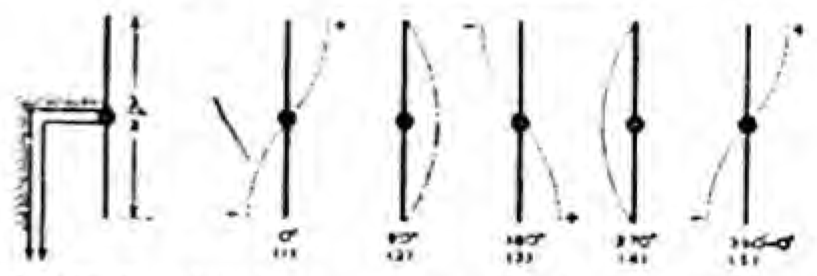
V (velocity)—300,000,000 metres per second
f (frequency)
λ (wavelength) in metres.

Wavelength and frequency are inversely proportional to each other, i.e. as one increases the other decreases since the velocity remains constant.

Obviously the wavelength of the travelling electro-magnetic wave must relate to the aerial in which it induces electric currents. And this is so. A conductor through which an oscillating current is flowing will show a variation in rise and fall of current flow along its length which for one complete cycle is the same as the wavelength of the electro-magnetic wave it radiates.

Nearly all aerials where frequency is high (as in TV) and the length of the aerial really important, are dipoles (two pole) of half a wavelength, fed at the centre.

Here are diagrams of a simple dipole aerial to show the stages in one cycle of oscillation.

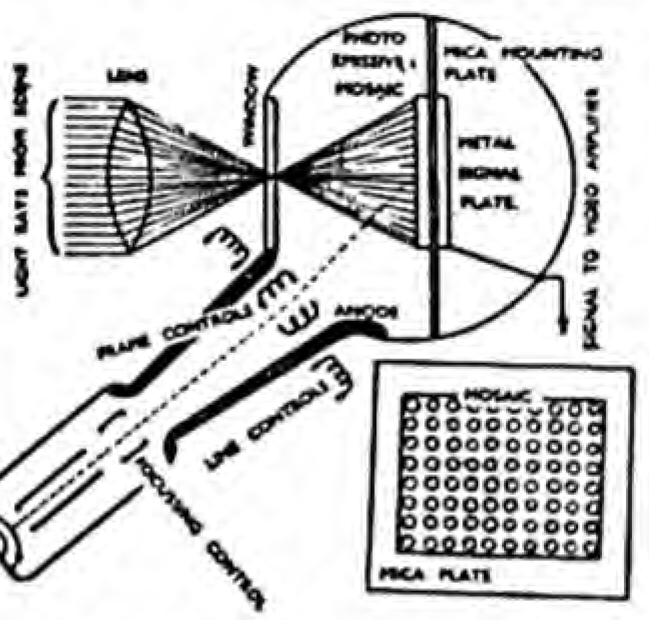


When the dipole is set into vibration (electrically) by the oncoming wave to which it is tuned (because of its length) the current and voltage amplitudes along it are plotted in the form of a graph over the whole cycle. It will be seen that the current will be at maximum at 90° and 270° and will appear in the centre where it is passed down the feeders into the receiver.

The wavelength of the resonant frequency of a tuned circuit is $\lambda = 1 \cdot 885 \sqrt{LC}$, where λ is in metres, L in μH and C in $\mu\mu$F and 1·885 is a constant used in the formula.

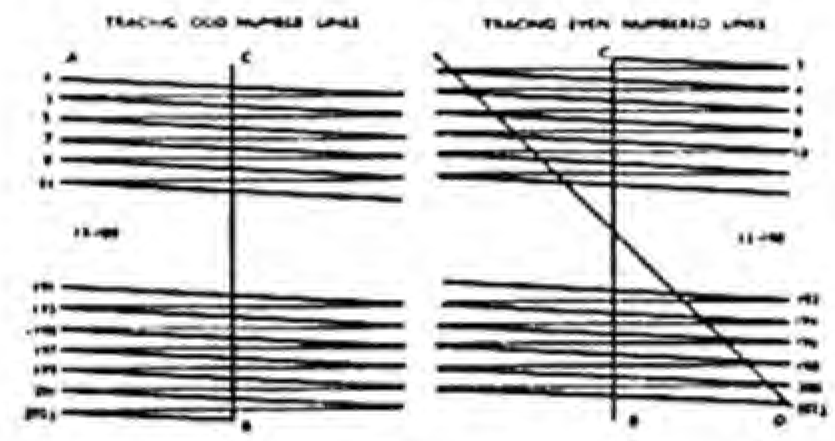
TELEVISION

The block diagram shows the sequence of events from the television camera to the viewing screen. Firstly there is the Camera, a special type of Cathode Ray Tube (C.R.T.) which looks something like this:



The photo-sensitive surface is known as the "Mosaic" and consists of thousands of tiny globules of the metal caesium deposited on a mica surface mounted on a metal back plate (signal plate). Each globule is insulated from its neighbours and behaves as a tiny photo-electric cell. When light falls on the cell it gives off electrons and is left with a positive charge. This Mosaic, mica and backplate form a very sensitive condenser which charges up to a potential proportionate to the amount of total light reaching each tiny cell at any instant. It works at very high speeds and discriminates between all shades in the range from black to white. One hundred per cent white passes most current and black passes none. The actual modulation range used is between 100% white down to 30% for black. The remaining 29% is used to cover up the sync pulses that control the line and frame and picture changes. These would otherwise be seen on the receivers and spoil the picture.

By means of special time-base and switch circuits the electron beam is made to move across and down the mosaic in an orderly fashion (called scanning). The B.B.C. system does it in 405 lines like this:



The lines across are traced slightly sloping downwards to the right so that the flyback does not retrace the line it has already made. The electron beam (the spot) commences at A line 1—is moved over to the right. Then line sync pulse makes the spot fly back to commence line 3—then over to the right again—another sync pulse and back to 5 and so on to line 202½, on which half-way over at B a frame sync pulse takes charge.

The spot shoots up from B to C to complete the first "even" half line. The spot carries on down again backwards and forwards until it gets to line 202½ at D. Another frame sync pulse causes the spot to fly diagonally back to A.

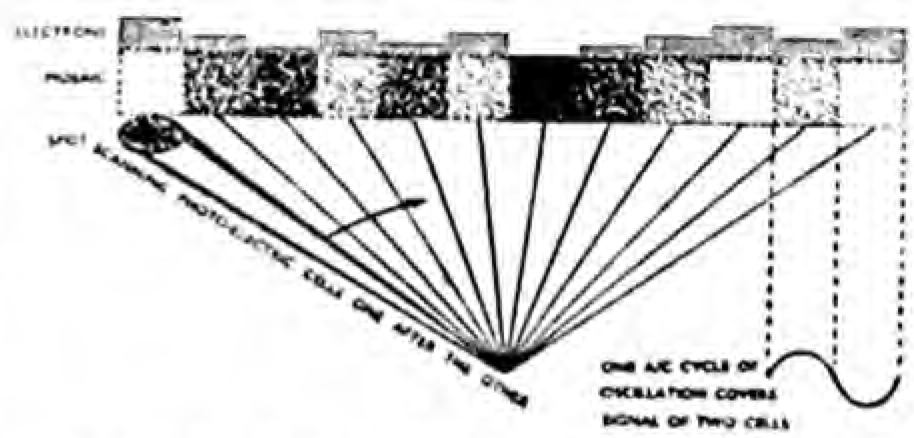
The two frames which make a complete picture are called a "Raster". This process of going twice over the mosaic is called "Interlacing scanning".

Only 377 lines are used (188½ in each frame) for the picture itself; the remainder are used to cover up the line, frame and picture changes.

The scan takes $\frac{1}{50}$ of a second, or for the two frames to make a complete picture $\frac{1}{25}$ of a second—approximately the same speed as cinema film is run. Since the human eye retains an image for about $\frac{1}{15}$ of a second 25 pictures per second appears as continuous without flicker.

The image of the scene being shot by the camera is focused on to the "mosaic", producing all the lights and shades in the scene. The electron beam scans every little photo-electric cell area in turn, neutralising its positive charge, and produces in each case a current from the condenser which is proportional to that charge, and therefore also proportional to the amount of light falling on each cell. This current is then passed on to the Video Amplifier.

Illustration of photo-electric cells or picture elements in one line (highly magnified) being scanned by the spot.



The number of cells or elements scanned can be determined from the known characteristics of a TV system. The B.B.C. picture aspect ratio is 4:3 (height is $\frac{3}{4}$ of the width), 405 lines, of which 377 are used.

So we get $\frac{377 \times 377 \times 4}{3} = 190{,}000$ approx.

At 25 pictures per sec. = 190,000 × 25 = 4,750,000 cells scanned per sec. This figure will determine the highest modulation frequency to be transmitted. In each complete cycle of an A.C. oscillation (~) two cells or elements can be covered as shown above, therefore the actual signal frequency will be one half of the number of cells scanned

per sec. $= \frac{4{,}750{,}000}{2} = 2 \cdot 35$ mc/s.

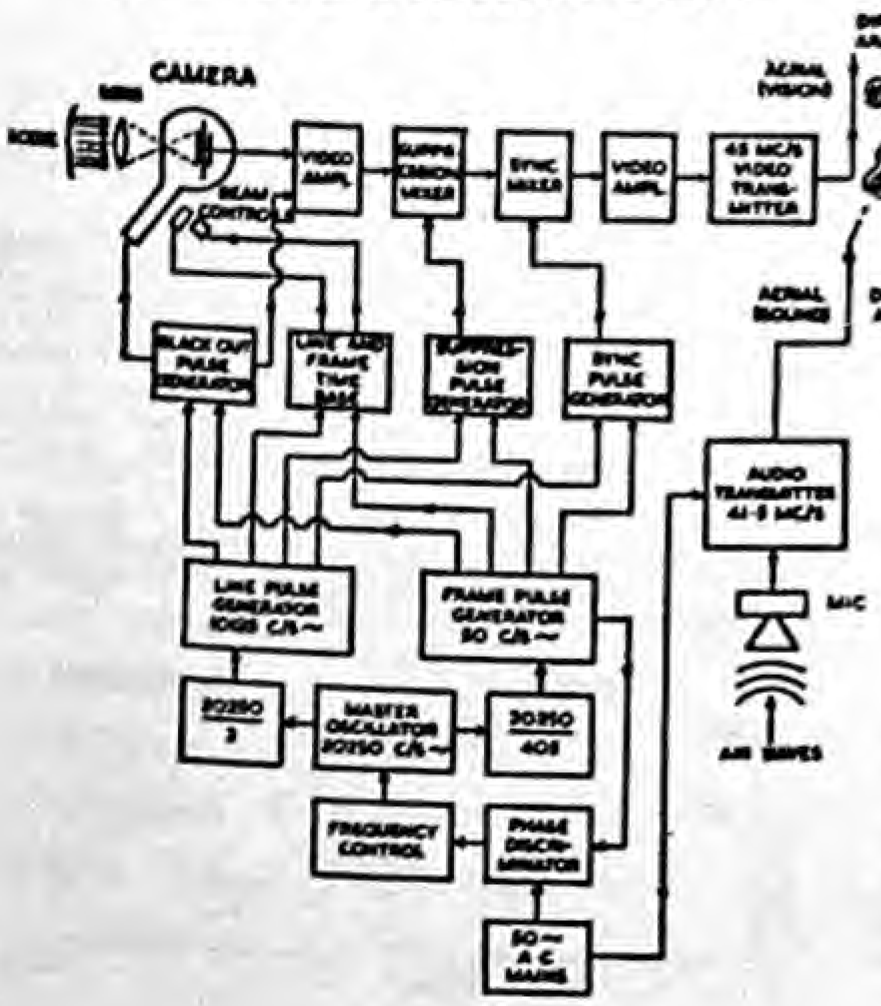
(Actual video signal used by B.B.C. London is 2·75 megacycles).

The video amplifier then passes the signal to various complicated networks of time bases, electronic switches and relays, etc., thence to the transmitter and finally to the aerial as shown in the block diagram of the sequence of events.

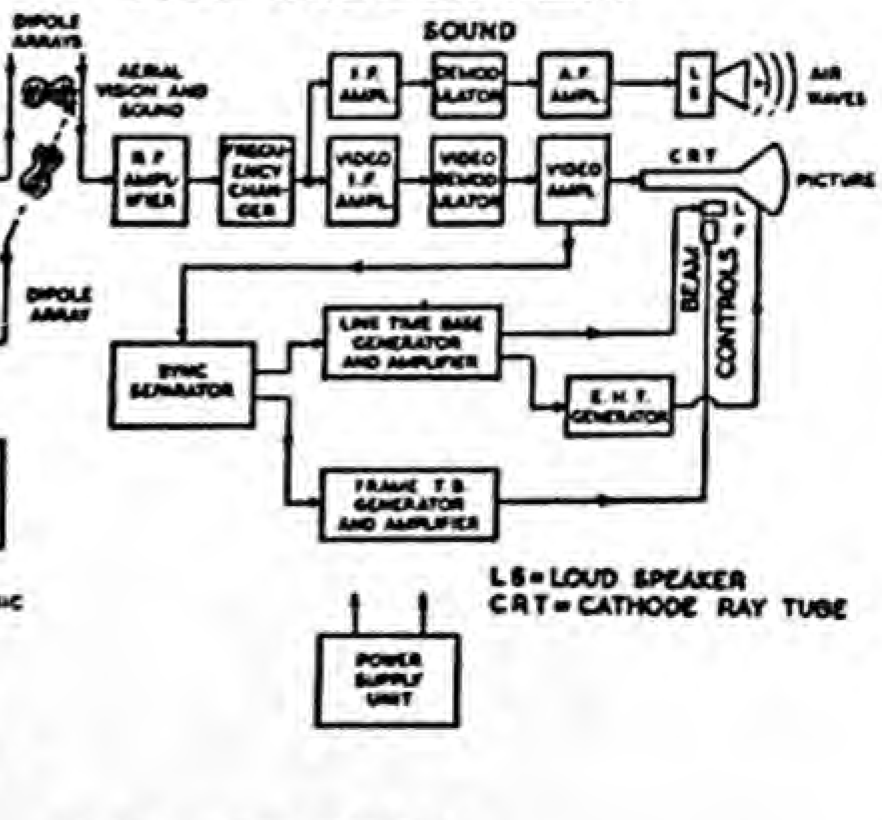
The sound signal is transmitted separately from the vision on a different frequency (41·5 mc/s. B.B.C. London) and from a second aerial.

The signals arrive at the receiver and in order to receive them properly a dipole aerial of the right design is needed. (*See* Aerials.) If the receiver aerial is not properly positioned in relation to the transmitter aerial some or all of the signals may be lost and the picture and sound spoiled.

T.V. TRANSMITTER



T.V. RECEIVER

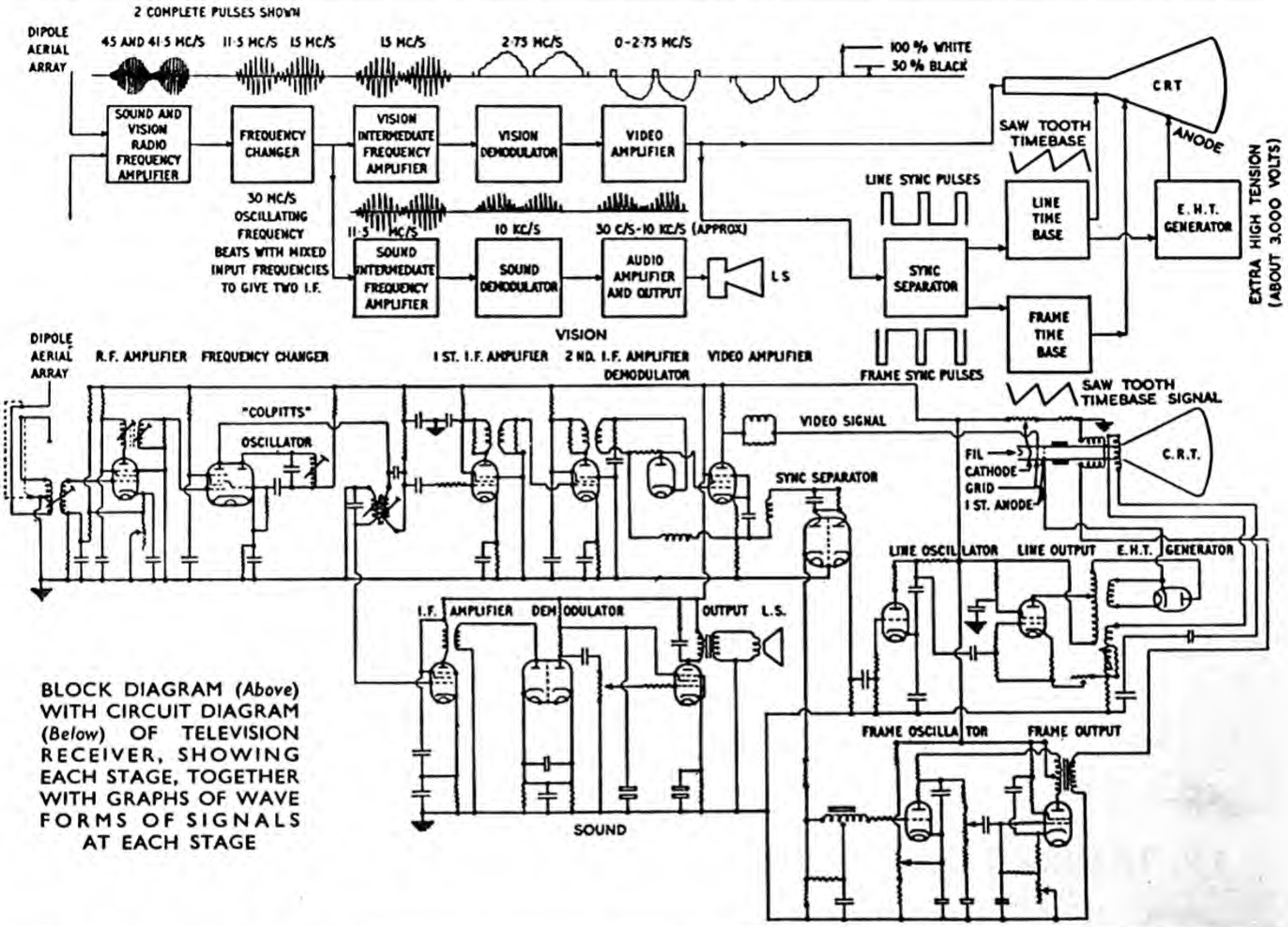


TRANSMISSION FREQUENCIES ARE BBC LONDON AREA

The signals induced in the aerial circuit being weak—only a few microvolts (μ Volts), they have to be passed through the RF Amplifier stage to bring them up to a reasonable working value. Then they are passed to the frequency changer where the sound and vision signals are separated and passed on to their respective channels at the two pre-determined I.F. (see Superhets, p. 205). The sound is treated in the same way as for radio, and passes on to the loudspeaker but, of course, it has to be kept synchronised with the vision.

The vision signals get similar treatment to the sound (demodulation and amplification) before being passed on to the grid of the CRT where they cause the electron beam to get stronger or weaker exactly in time with the camera beam, and the electrons striking the fluorescent screen cause it to glow brighter or darker reproducing what appears on the TV camera "mosaic".

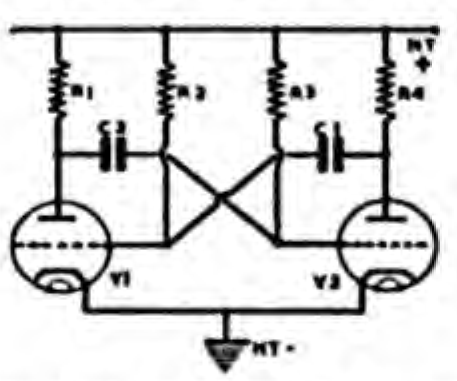
Now as there are some 4,750,000 variations to be passed onto the fluorescent screen in one second, it is made to stay in a state of fluorescence for a period of 1 second. At the same time the sync (synchronising, i.e. triggering the receiver beam in time with the camera beam) pulses have to be separated from the video signal in the sync separating stage, which passes the "Line" signals to the "Line time-base generator" and amplifier. The L.T.B.G. has to produce 10,125 lines every second exactly in time with the camera line time-base generator. The frame signals are passed to the F.T.B.G. and amplifier which has to produce 50 frames (25 complete pictures) per second exactly in time with the camera F.T.B.G. These two sets of signals are then passed to the deflector coils on the C.R.T. which control and position the electron beam exactly in step with the camera electron beam.



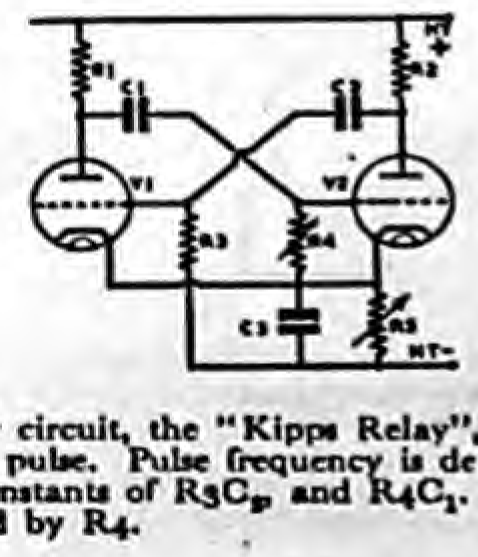
BLOCK DIAGRAM (*Above*) WITH CIRCUIT DIAGRAM (*Below*) OF TELEVISION RECEIVER, SHOWING EACH STAGE, TOGETHER WITH GRAPHS OF WAVE FORMS OF SIGNALS AT EACH STAGE

"SAW TOOTH" TIME-BASE OSCILLATORS

Multivibrator: Two valves coupled in a permanently unstable condition. On connecting the supply



one valve (say V1) becomes highly conductive; its grid, anchored to the positive end of the supply, has no control over valve current, which rises to saturation. Due to this heavy current across R1 the anode voltage will rapidly fall. Through C2 this sudden downward movement of voltage is passed to the grid of V2, which becomes suddenly cut off. Gradually, however, C2 will be recharged from the supply through R3 and with it the grid voltage of V2 will rise, passing more current in V2 and therefore lowering the voltage at the anode of V2. This drop again is passed on to the grid of V1 through C1, so that V1 now performs in the same way as V2. This process will go on indefinitely, the two valves becoming alternatively conductive. The *frequency* of oscillation will be determined by the *time constant* of the resistance—capacitance combinations R_1C_1 and R_3C_2.



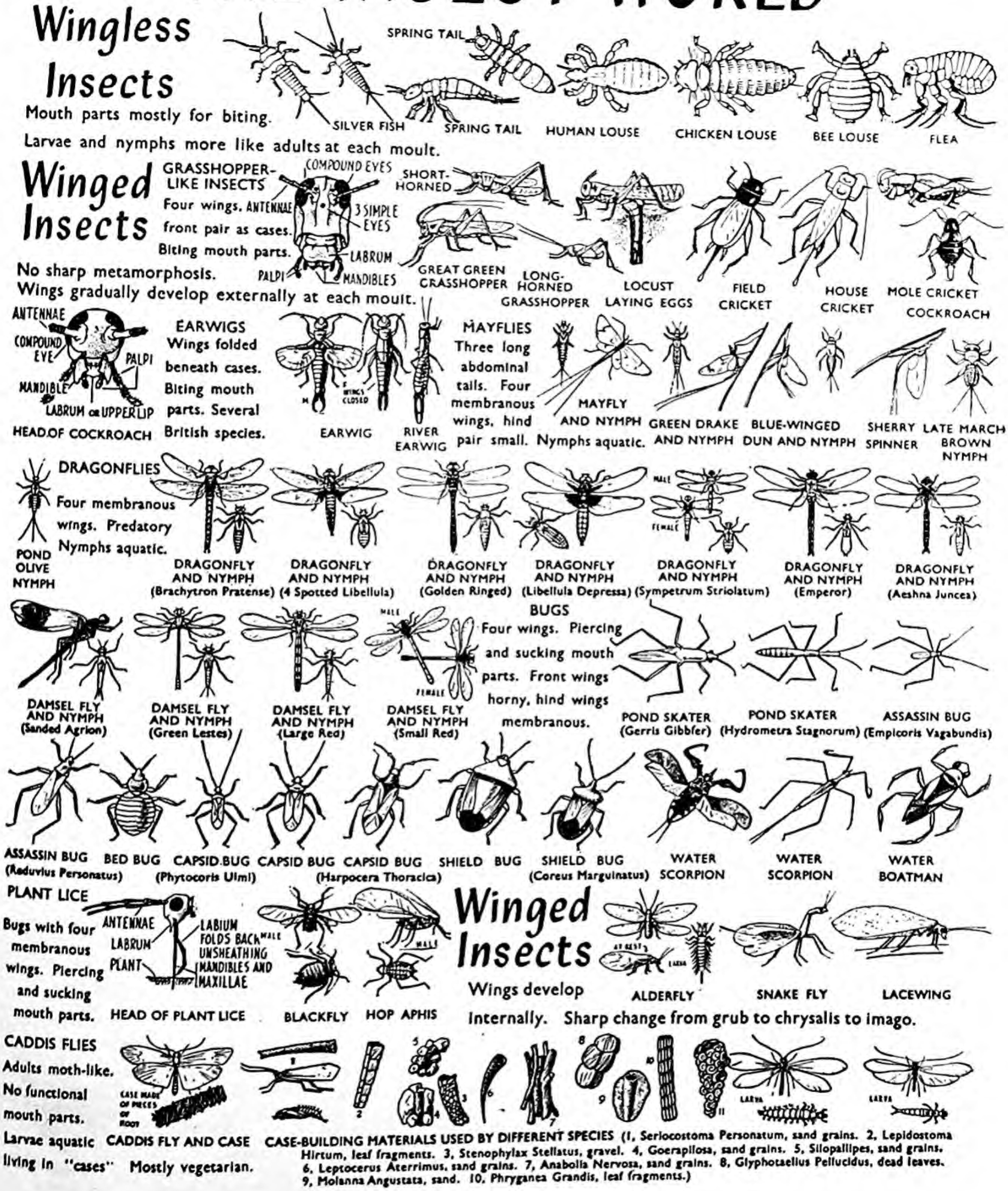
A similar circuit, the "Kipps Relay", produces a rectangular pulse. Pulse frequency is determined by the time constants of R_3C_2, and R_4C_1. Pulse width is controlled by R4.

TIME CONSTANTS OF TIME-BASE CIRCUITS

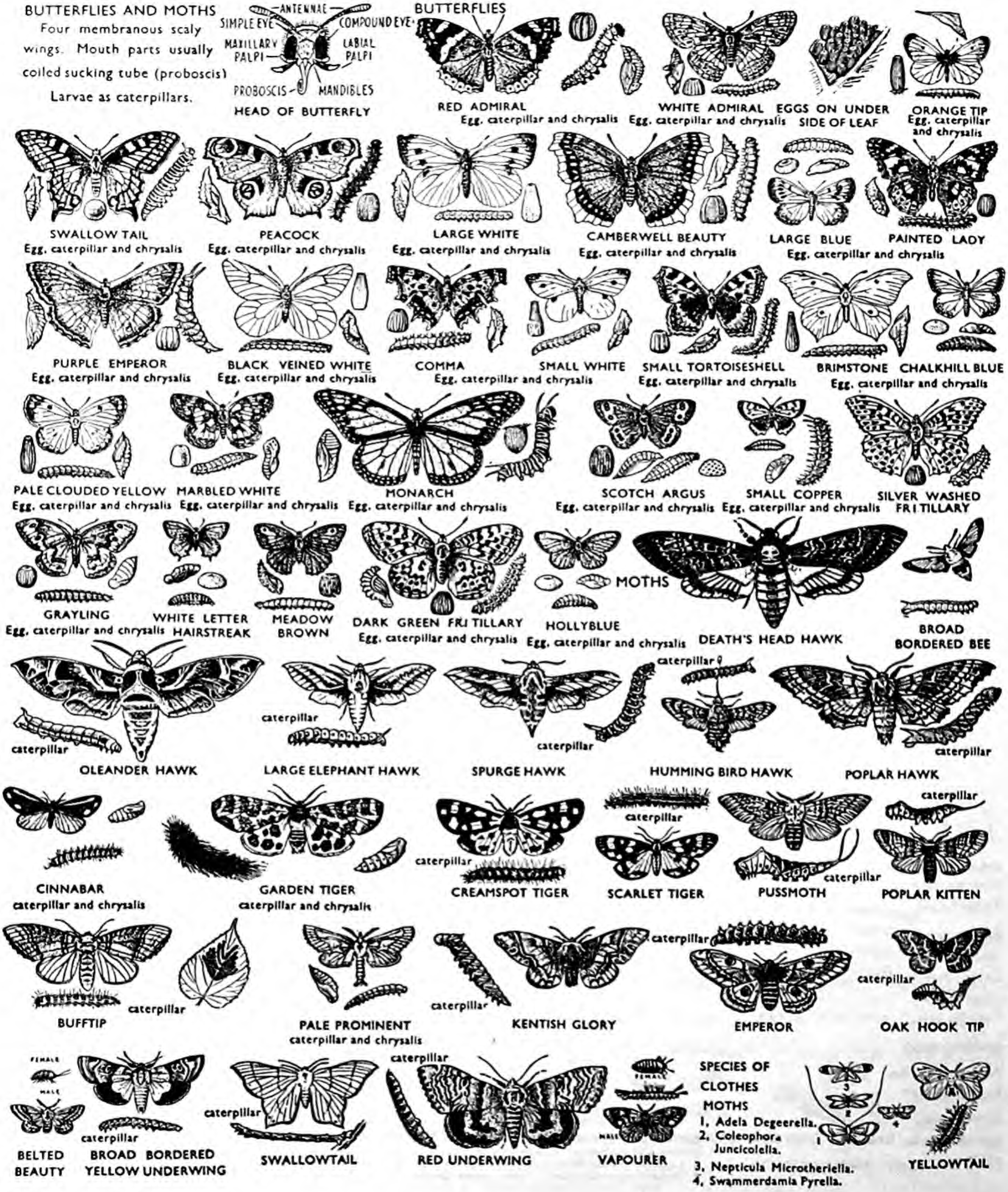
On application of a D.C. E.M.F. there is an *instantaneous* flow of current into (but *not* through) the uncharged condenser, rapidly rising to maximum. The accumulating negative charge (i.e. of electrons) on one of the plates results in the development of a back E.M.F., which quickly reduces the current flow to zero. The voltage accumulated across the plates correspondingly increases to a maximum, equal to the applied E.M.F.

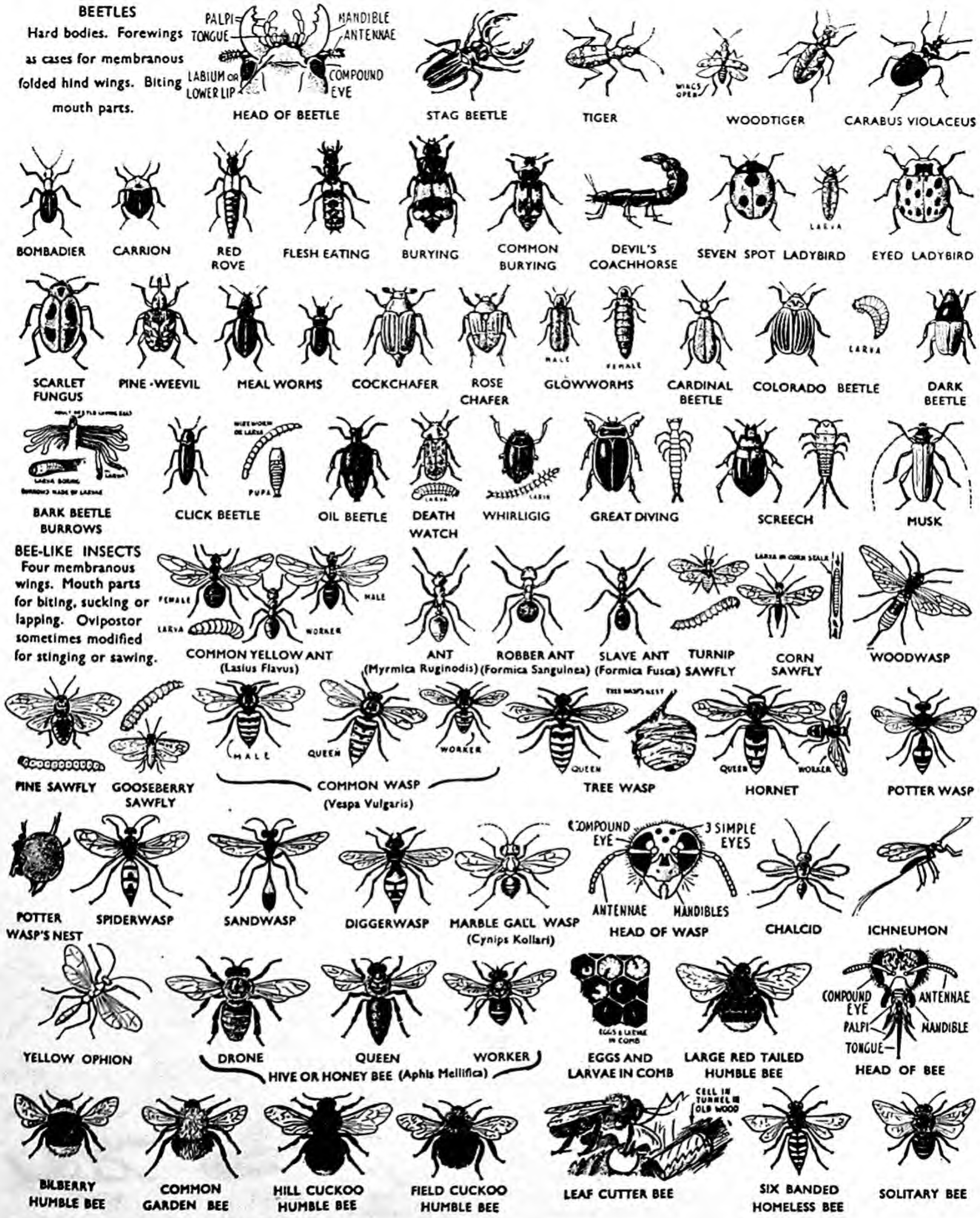
If the condenser is then discharged through a high resistance, the current flow will vary in reverse of the charging. The values of C and R decide the time taken.

THE INSECT WORLD



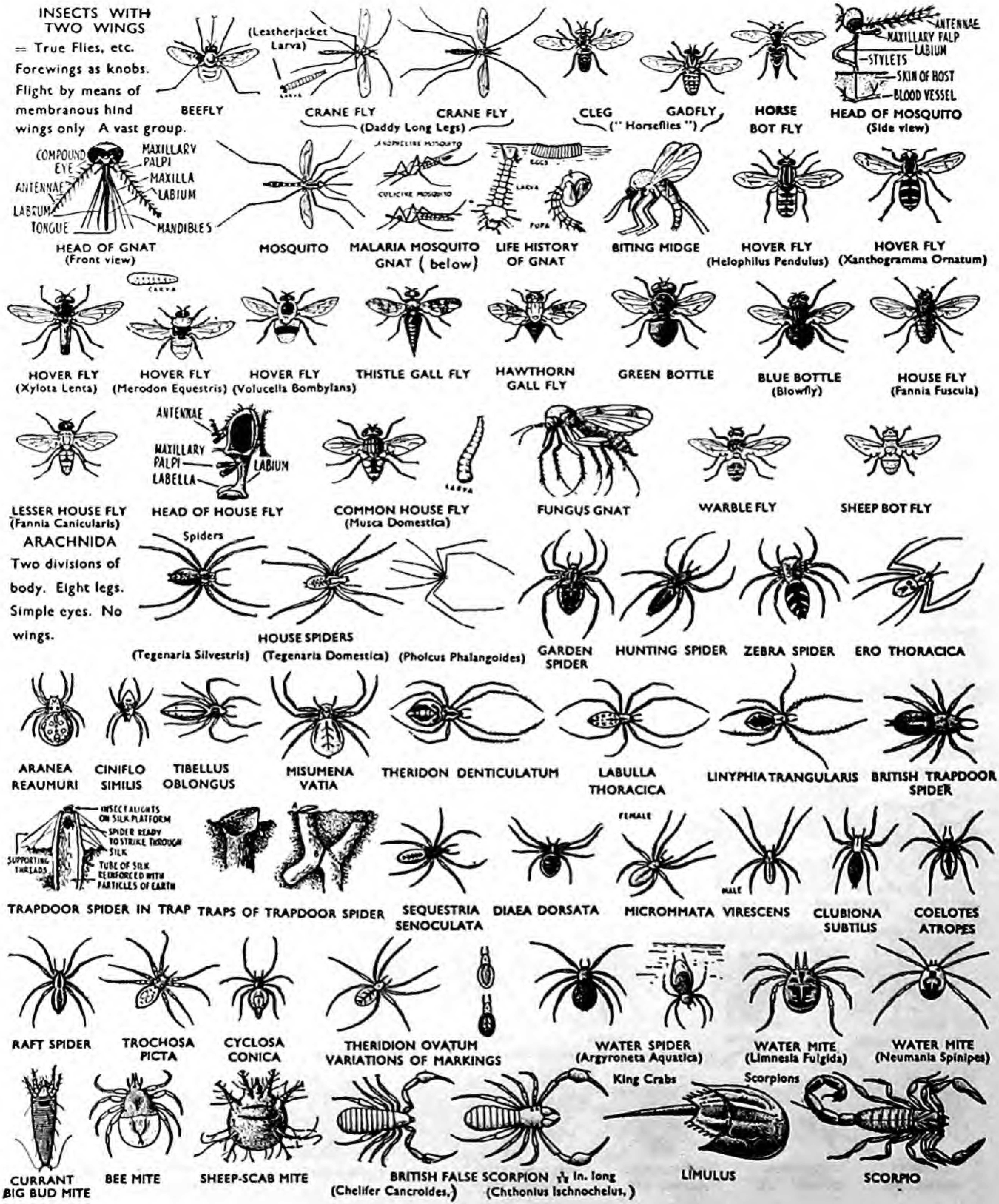
BUTTERFLIES AND MOTHS
Four membranous scaly wings. Mouth parts usually coiled sucking tube (proboscis) Larvae as caterpillars.




BEETLES
Hard bodies. Forewings as cases for membranous folded hind wings. Biting mouth parts.
PALPI
TONGUE
MANDIBLE
ANTENNAE
LABIUM OR LOWER LIP
COMPOUND EYE
HEAD OF BEETLE
STAG BEETLE
TIGER
WINGS OPEN
WOODTIGER
CARABUS VIOLACEUS
BOMBADIER
CARRION
RED ROVE
FLESH EATING
BURYING
COMMON BURYING
DEVIL'S COACHHORSE
SEVEN SPOT LADYBIRD
LARVA
EYED LADYBIRD
SCARLET FUNGUS
PINE-WEEVIL
MEAL WORMS
COCKCHAFER
ROSE CHAFER
MALE
FEMALE
GLOWWORMS
CARDINAL BEETLE
COLORADO BEETLE
LARVA
DARK BEETLE
BARK BEETLE BURROWS
CLICK BEETLE
WIREWORM OR LARVA
PUPA
OIL BEETLE
LARVA
DEATH WATCH
LARVA
WHIRLIGIG
GREAT DIVING
SCREECH
MUSK
BEE-LIKE INSECTS
Four membranous wings. Mouth parts for biting, sucking or lapping. Ovipostor sometimes modified for stinging or sawing.
FEMALE
MALE
LARVA
WORKER
COMMON YELLOW ANT
(Lasius Flavus)
ANT
(Myrmica Ruginodis)
ROBBER ANT
(Formica Sanguinea)
SLAVE ANT
(Formica Fusca)
TURNIP SAWFLY
LARVA IN CORN STALK
CORN SAWFLY
WOODWASP
PINE SAWFLY
GOOSEBERRY SAWFLY
MALE
QUEEN
WORKER
COMMON WASP
(Vespa Vulgaris)
TREE WASP'S NEST
QUEEN
TREE WASP
QUEEN
WORKER
HORNET
POTTER WASP
POTTER WASP'S NEST
SPIDERWASP
SANDWASP
DIGGERWASP
MARBLE GALL WASP
(Cynips Kollari)
COMPOUND EYE
3 SIMPLE EYES
ANTENNAE
MANDIBLES
HEAD OF WASP
CHALCID
ICHNEUMON
YELLOW OPHION
DRONE
QUEEN
WORKER
HIVE OR HONEY BEE (Aphis Mellifica)
EGGS & LARVAE IN COMB
EGGS AND LARVAE IN COMB
LARGE RED TAILED HUMBLE BEE
COMPOUND EYE
ANTENNAE
PALPI
MANDIBLE
TONGUE
HEAD OF BEE
BILBERRY HUMBLE BEE
COMMON GARDEN BEE
HILL CUCKOO HUMBLE BEE
FIELD CUCKOO HUMBLE BEE
CELL IN TUNNEL IN OLD WOOD
LEAF CUTTER BEE
SIX BANDED HOMELESS BEE
SOLITARY BEE

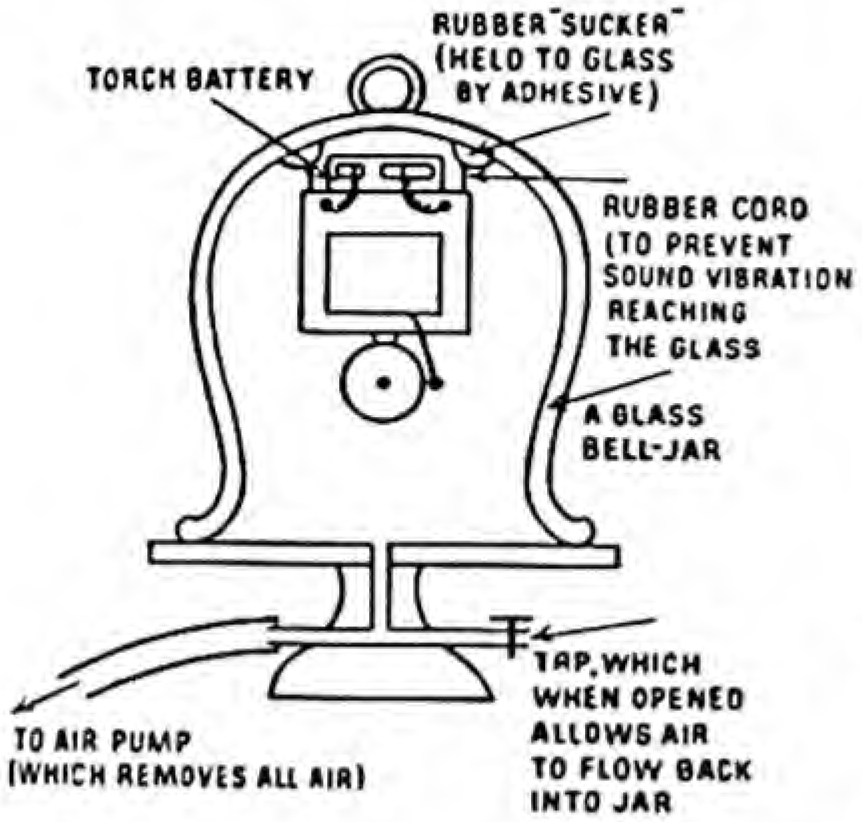
INSECTS WITH TWO WINGS
= True Flies, etc.
Forewings as knobs.
Flight by means of membranous hind wings only. A vast group.

ARACHNIDA
Two divisions of body. Eight legs. Simple eyes. No wings.



SOUND

THE TRANSMISSION OF SOUND

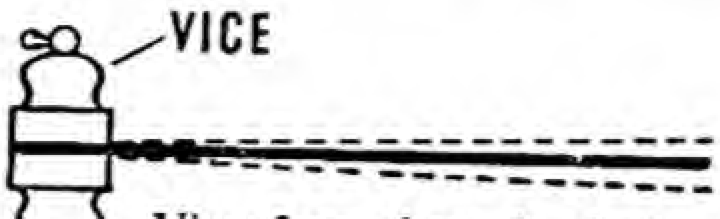


(1) Sound cannot travel through empty space (vacuum). The ringing of the bell can be heard through the glass cover until the air is pumped out. The sound is heard again as the air is allowed to return. Sound normally travels through the *air* to our ears.
(2) Sound also travels through solids. The ticking of a watch resting on a table can be heard by placing the ear against the table top.
(3) Sound also travels through liquids. Tapping on the side of a bath is heard very clearly when both ears are under the water.
(4) Sound can be transmitted by the human skull. The tapping of a pencil on the teeth and the ticking of a watch held against the forehead are clearly audible even with cotton wool in the ears.

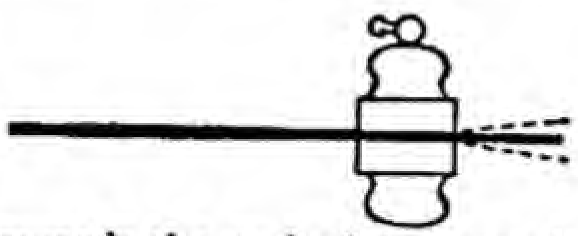
The sensation of sound is the result of stimulating, by means of vibration, a series of nerve-endings, housed in the skull. These effects are interpreted by the brain as sounds. Normally, sound waves in air enter the ear, and vibrate the ear drum. These vibrations are transmitted to the nerve-endings by tiny bones acting as levers.

Sound is the result of movement.
Examples: No wind: no rustle of leaves, no howling in a chimney.
Violin string still, no note. String set into movement by bow, note produced. Vibration stopped by pressing on middle of string with finger, and note dies away.

All movements do not produce sound. The springy strip of steel is held tightly in a vice, first at one end and then, step by step, towards the other end. The free end (the same end throughout the experiment) is pulled to one side and released. The strip vibrates, taking some time to come again to a standstill. When the vibrating length is very long, it moves very slowly and produces no note. As it is shortened, it vibrates more



View from above (a plan).
(a) the beginning of the experiment.



(b) towards the end of the experiment.

quickly and produces a deep hum. Still further shortened, the vibrations are more rapid and the note rises up the scale.

The pitch of a note is determined by the frequency of vibration, i.e. the number of complete vibrations per second.

The loudness of a note is determined by the strength, or *amplitude*, of the vibrations.

The quality of a note. Exactly the same note sung, in tune, by different people, and played on piano, flute, violin or other musical instrument sounds quite different. In every case, not only is the note itself (the fundamental) being produced, but a whole series of other (higher) notes (the overtones or harmonics). These vary from voice to voice and from instrument to instrument, thus giving "quality".

The result is musical, because the harmonics are related by simple whole-number ratios to the fundamental.

This is not so in drums and other percussion instruments, where the harmonics (overtones) are produced as part of a circle (see p. 39), not as divisions of a length as in a string or a pipe, so the frequency relationship of the notes of a drum is not simple and the result is a noise, not a musical sound, though it can be tuned to the same fundamental frequency as a musical note.

THE LIMITS OF AUDIBILITY. The rates of vibration which produce the sensation of sound vary from person to person, and, for the same person, with age. Some people are oblivious to the high-pitched whine of a mosquito's wings, while others are infuriated by it.

Average values:
Lower limit of audibility: 20 vibrations per second.
Upper limit of audibility: 25,000 vibrations per second.

Animals clearly have different limits—there is a special high-pitched whistle used for calling dogs at night—quite inaudible to human beings.

SUPERSONIC OR ULTRASONIC VIBRATIONS. These are vibrations fast enough to be above the upper limit of audibility. Much use is being made of them, e.g. in echo sounding. The pitch of a note is expressed by the number of vibrations (or cycles) per second.

SOME INTERESTING FREQUENCIES

	pitch
"Middle C" on the piano	261·5
Lowest note on the piano (A)	27·5
Highest note on the piano (A)	3,520
Lowest note on organ (64 ft. pipe)	8
Highest note in the orchestra (piccolo)	4,752

THE SPEED OF SOUND IN AIR. This increases a little with rise in temperature. It does not depend on air pressure.

At 0°C.: 1,085 ft. per sec. or 740 m.p.h. or 331 m. per sec.

At 18°C.: 1,120 ft. per sec. or 765 m.p.h. or 342 m. per sec.

Note: The speed of sound in air at norma temperatures is approximately 1 mile in 5 seconds.

Calculation 1: A coastguard heard a ship's siren 20 sec. after he saw the "steam" (really drops of water) emitted from it. How far away was the ship?

(a)

$$765 \text{ m.p.h.} = \frac{765}{60 \times 60} \text{ miles per sec.}$$

$$\therefore \text{ distance in 20 sec.} = \frac{765 \times 20}{60 \times 60}$$

$$= 4{\cdot}25 \text{ miles.}$$

(b) Mental method:
1 mile in 5 sec.
$\therefore$ 4 miles in 4 times 5 sec.

Calculation 2: The "crack" of thunder (the sharp sound preceding the long rumble in a peal of thunder) is the noise of the flash of lightning. If it is heard 10 seconds after the flash is seen, how far away is the storm? 10 sec. is twice 5 sec. $\therefore$ it represents the time for sound to travel twice one mile, i.e. 2 miles.

Calculation 3: An inexperienced timekeeper for a 100 yd. race stood at the finishing line and started his stop-watch when he heard the sound of the starter's gun (instead of when he saw the flash). What error would this make in the timing?

100 yd. = 300 ft.

$$300 \text{ ft. at 1,120 ft. per sec. takes } \frac{300}{1{,}120} \text{ sec.}$$

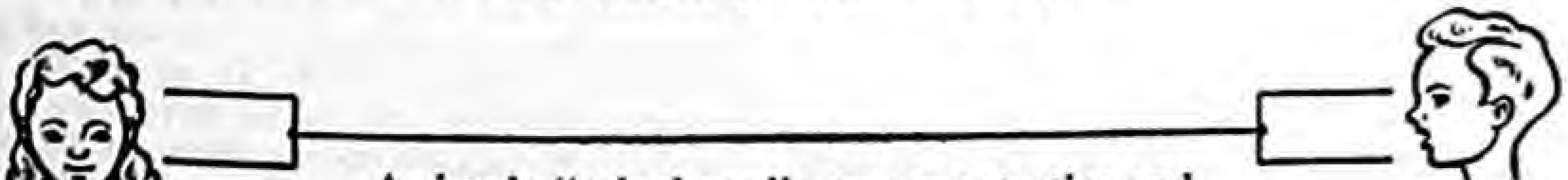
$= {\cdot}3$ sec. approx.

$\therefore$ he started his watch $\frac{3}{10}$ second after the race had begun, so he should add $\frac{3}{10}$ sec. to the time recorded.

Supersonic speed is a speed in air greater than that of sound. A "supersonic aircraft" is one that travels through air faster than the normal speed of sound.

The "Sound Barrier" refers to difficult flying conditions which may be encountered as the speed of the aircraft approaches that normal for sound.

Note: For very rapidly moving bodies, e.g. bullets, the sound of their passage travels along with them instead of at the normal speed of sound in air.



A simple "telephone"—two empty tins and a taut length of string, showing that string is a good conductor of sound.

SOME SPEEDS OF SOUND

Substance	*ft. per sec.*	*m.p.h.*	*metres per sec.*
Fresh water	4,620	3,150	1,410
Sea water	5,050	3,450	1,540
Iron	16,400	11,200	5,000
Wood (average)	13,000	8,900	4,000

Calculation: An underwater bell is struck, at a lighthouse, at the same instant as a warning signal is sent by radio. The note of the bell is heard on a ship (by special underwater listening apparatus) four seconds after the radio signal is received. How far away is the ship from the lighthouse? Reckon radio as instantaneous.

4 sec. at 5,050 ft. per sec.

$$= 20{,}200 \text{ ft.} = \frac{20{,}200}{5{,}280} \text{ miles} = 3{\cdot}8 \text{ miles.}$$

ECHOES. When a sound wave leaves its source and is reflected back by an obstruction (e.g. a cliff, a building) the result is an echo. The time between the sound being produced and heard again as an echo is the time taken for sound to perform a double journey, out to the obstruction and back again. Thus a cliff one mile away would produce an echo of a gun shot 10 sec. later (10 sec. being the time required for sound to travel *two* miles in air).

Echoes are often heard (without realising it) in theatres, concert halls, churches and other large buildings. The speaker's words may be heard again a fraction of a second after first hearing them, sometimes making it very difficult for an audience to understand one word while it is accompanied by the echo of the previous word. A hall in which it is difficult to hear because of echoes is said to have bad "acoustics". Nowadays the acoustics of a building are tested on small models, which can be altered at little cost, before the construction of the building itself is commenced.

ECHO SOUNDING. Vibrations (often supersonic) are set up by a special generator in the bottom of the ship. These travel to the sea-bed and return, as an echo, some time later, depending upon the depth of the water. They are picked up by a microphone and fed to an apparatus which makes, on a moving roll of paper, a contour map of the sea-bed as the ship steams over it. Echo-sounding is valuable in ordinary navigation, in locating wrecks, and in finding shoals of fish like herring, which reflect back the sound waves before they can reach the bottom.

Calculation: In an echo-sounder, the interval between the transmission of a signal and the receipt of an echo is 10 sec. How deep is the sea?

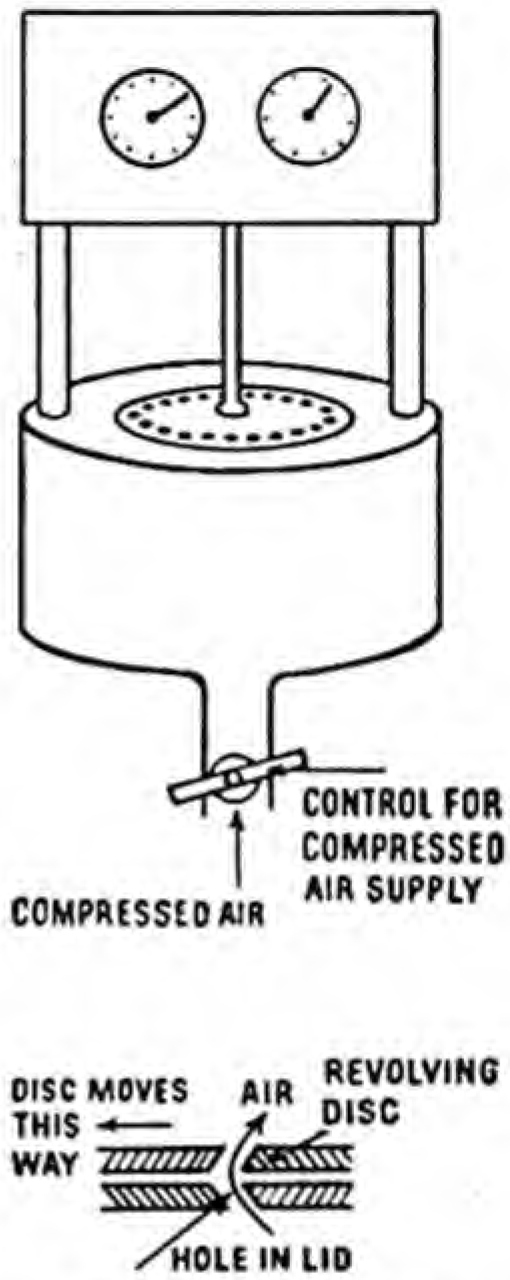
Time for return journey = 10 sec.

∴ Time for single journey = 5 sec.

Distance of single journey, 5 sec. at 5,050 ft. per sec. = 25,250 ft. = 4·8 miles approx.

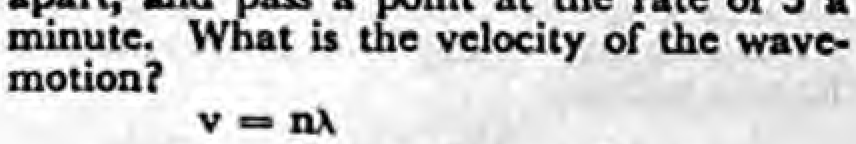
THE SIREN. In this instrument the air is set into vibration by a regular series of puffs of air, each released as a hole in a revolving metal plate passes over a fixed hole in a box of compressed air. The holes are shaped so that the rush of air also drives the revolving disc, its speed being controlled by the air pressure inside the "chest" of air. In the laboratory model there is a dial (rather like that on a gas or electric meter) to help calculate the number of revolutions per sec.

If, to produce a certain note, a disc with 50 holes in it has to go round 20 times in a second, then there are 20 × 50 = 1,000 puffs of air per second, and the pitch of the note is 1,000.



A siren for experimental purposes.

WAVE-LENGTH AND FREQUENCY. If, at the seaside, we could measure the distance between the crest of one wave and the next, we would have the "*wave-length*" λ (pronounced "lambda").



If we count the number of waves passing a point in unit time, e.g. 1 minute, we have the "*frequency*", (n).

Since n crests, each λ apart, pass in unit time, the velocity (v) of the wave is nλ.

$$v = n\lambda.$$

Example: The crests of a wave are 30 ft. apart, and pass a point at the rate of 5 a minute. What is the velocity of the wave-motion?

$$v = n\lambda$$
$$\therefore v = 5 \times 30 \text{ ft. per minute}$$
$$= 150 \text{ ft. per min.}$$

Although the waves in air are "to and fro" (longitudinal), rather than "up and down" (transverse), the same law holds good.

Example: What is the wave-length set up in the air by a tuning fork of pitch 440?

n = 440 vibrations (or cycles) per sec.

v = 1,120 ft. per sec.

$v = n\lambda.$

$$\therefore 1{,}120 = 440\lambda$$

$$\therefore \lambda = \frac{1{,}120}{440} = 2{\cdot}5 \text{ ft.}$$

THE NOTES OF THE SCALE. The human mind is very expert at judging the relationship between a series of notes, and even a slight mistake in pitch for one of them is very displeasing. The relationships which are pleasing are arranged in a scale:

doh, ray, me, fah, soh, lah, te, doh.

When the frequencies are compared, the following are the ratios:

The Diatonic Scale

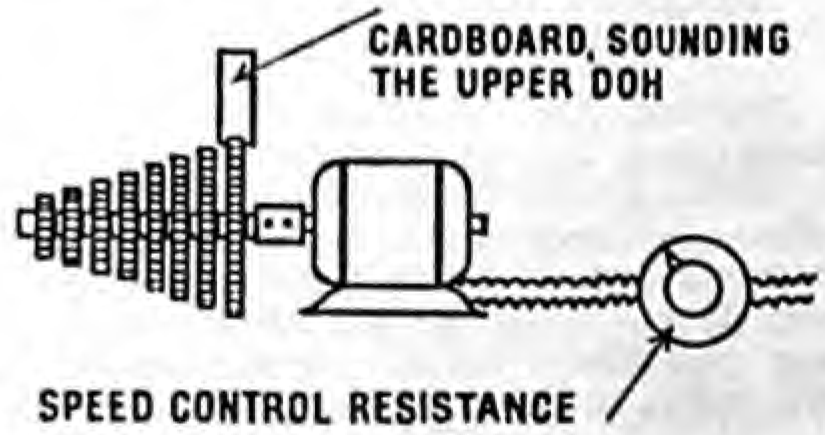
doh	ray	me	fah	soh	lah	te	doh
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

e.g. if Doh has a pitch of 240, the notes which sound correct for a scale have frequencies as follows:

doh	ray	me	fah	soh	lah	te	doh
240	270	300	320	360	400	450	480

cycles per second.

This can be checked, very readily, using the laboratory siren or a special demonstration musical instrument consisting of eight cogwheels on the shaft of an electric motor, notes being produced by holding a postcard against the teeth of each wheel in turn. The cogwheels have 24, 27, 30, 32, 36, 40, 45 and 48 teeth respectively and produce a perfect scale.



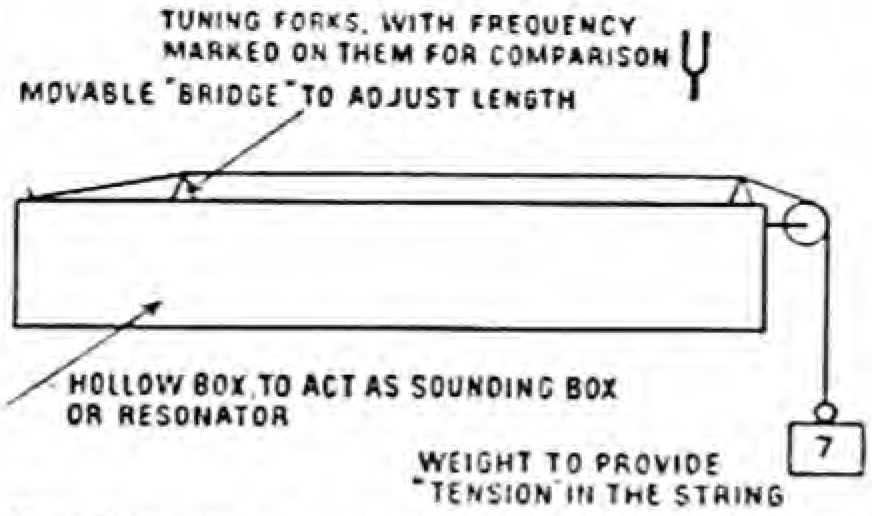
The cogwheels play a perfect scale whatever the speed of the motor. The speed is adjusted (by means of the resistance) to control the "key" of the scale.

The music of the pianoforte is produced by felt-covered wooden hammers striking metal wires stretched across an iron frame. For a particular note, the string is of a predetermined thickness and length: it is tuned by adjusting its tension.

Difficulties arise with the diatonic scale when the pianoforte is used, for if the piano is made and tuned to give a perfect scale starting, say, with note C as Doh, the result is most displeasing if we try and play the scale starting with D as Doh. The compromise adopted is an *equitempered scale*, which, although it never gives the relationships exactly right, is always sufficiently near, in scales beginning on any note, never to be really displeasing.

Concert pitch. Almost all ears are offended by notes played out of tune, i.e. with the wrong relationship to others. The majority of listeners do not worry about the actual frequencies used (i.e. the "key" of the music) so long as the relationship between the notes is correct. Thus, until 1929, military band instruments were tuned to a higher key than those of an orchestra, so they could never play together. By international agreement, in correct Concert Pitch, the A above middle C of the piano has a frequency of exactly 440 cycles per sec. (c.p.s.).

Experiments with stringed instruments



The Sonometer, a single-stringed instrument used in a Physics laboratory. The string is plucked or bowed at its centre.

THE SCALES COMPARED

$$\text{Ratio} = \frac{\text{frequency of note}}{\text{frequency of Doh}}$$

Scale	Doh	Ray	Me	Fah	Soh	Lah	Te	Doh
Diatonic (ratio)	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Diatonic (decimals)	1·000	1·125	1·250	1·333	1·500	1·667	1·875	2·000
Equi-tempered	1·000	1·122	1·260	1·335	1·498	1·682	1·888	2·000

THE CHROMATIC SCALE

The Chromatic Scale, in use today, is an equi-tempered scale. It has thirteen notes in the octave, and a scale, taking any note as Doh, may be played and found to be pleasing.

FREQUENCIES OF NOTES ON THE CHROMATIC SCALE, CONCERT PITCH

The octave above "middle C"*

C*	D♭	D	E♭	E	F	G♭	G	A♭	A	B♭	B	C
261·5	277	293	311	329·5	349	370	392	415	440	466	494	523

Note. D♭ (D Flat) is the black key between C and D (white keys)
G♭ (G Flat) is the black key between F and G (white keys)
The "interval" between successive notes on the Chromatic Scale is a "semi-tone". The interval between a note and the one after next is a "tone".

SOME EXAMPLES OF HOW THE CHROMATIC SCALE GIVES A FULL RANGE OF "KEYS" ON THE PIANOFORTE

Scale in Key	DOH	RAY	ME	FAH	SOH	LAH	TE	DOH
		1 tone 2 notes	1 tone 2 notes	1 (semi-tone) 1 note	1 tone 2 notes	1 tone 2 notes	1 tone 2 notes	1 (semi-tone) 1 note
C	C	D	E	F	G	A	B	C
D	D	E	G♭	G	A	B	D♭	D
A	A	B	D♭	D	E	G♭	A♭	A

Note. The black key between F and G (for example) can be called either G Flat (G♭) or F Sharp (F♯). To simplify this explanation of the Chromatic Scale, the black keys have been given only one name.

Results :

1. *Effect of length* (tension being unchanged). Bridge is moved.

Change in length	*Effect on note*	*Change in frequency*
Doubled (× 2)	Octave lower	× ½
Halved (× ½)	Octave higher	× 2
Made two-thirds $\left(\times \frac{2}{3}\right)$	Doh → Soh	$\times \frac{3}{2}$

The frequency of a vibrating string is inversely proportional to its length; i.e.

$$n \propto \frac{1}{l}$$

2. *Effect of tension* (length being unchanged). Weights are changed.

Change in tension	*Effect on note*	*Change in frequency*	*N.B.*
Four times (× 4)	Octave higher	× 2	$2 = \sqrt{4}$
Nine times (× 9)	Soh of octave higher	× 3	$3 = \sqrt{9}$
A quarter (× ¼)	Octave lower	× ½	$\frac{1}{2} = \sqrt{\frac{1}{4}}$

The frequency of a vibrating string is directly proportional to the square root of the tension, i.e.

$$n \propto \sqrt{T}.$$

3. *Effect of the mass (per unit length) of the string.* Length and tension being unchanged.

Thinner and thicker strings are fitted, the same length and tension being used.

Mass of string	*Effect on note*	*Change in frequency*	*N.B.*
Four times (× 4)	Octave lower	× ½	$\frac{1}{2} = \frac{1}{\sqrt{4}}$
Nine times (× 9)	Doh → Fah 2 octaves lower	× ⅓	$\frac{1}{3} = \frac{1}{\sqrt{9}}$
A quarter (× ¼)	Octave higher	× 2	$2 = \frac{1}{\sqrt{\frac{1}{4}}}$

The frequency of a vibrating string is inversely proportional to the square root of mass per unit length (m), i.e.

$$n \propto \frac{1}{\sqrt{m}}$$

Combined, $n \propto \frac{1}{l}\sqrt{\frac{T}{m}}$

Example 1: The vibrating string of a musical instrument is 12 in. long and sounding Doh. What length should it be made to sound Soh?

$$\frac{\text{Soh}}{\text{Doh}} = \frac{3}{2}$$

$$n \propto \frac{1}{l} \therefore \frac{n_1}{n_2} = \frac{l_2}{l_1} \therefore \frac{2}{3} = \frac{l_2}{12}$$

$\therefore 2 \times 12 = 3 \times l_2$

$\therefore l_2$ (the second length) $= 8$ in.

Example 2: A stretched string is vibrating at 100 vibrations per second under a tension of 2 lb. With what frequency would it vibrate under a tension of 32 lb.?

$$n \propto \sqrt{T}$$

$$\therefore \frac{n_1}{n_2} = \sqrt{\frac{T_1}{T_2}} \therefore \frac{100}{n_2} = \sqrt{\frac{2}{32}} = \sqrt{\frac{1}{16}} = \frac{1}{4}$$

$\therefore 4 \times 100 = n_2$

$\therefore n_2$ (the second frequency) $= 400$ c.p.s.

Overtones in stringed instruments

String at rest.

String set into vibration to sound its fundamental note n, (Doh).

String also vibrates like this. Half wave-length $\therefore$ double frequency. Note of 2n as well (Doh an octave higher).

Also like this. $\frac{1}{3}$ wave-length $\therefore$ note of 3n as well (Soh in upper octave).

Also like this. $\frac{1}{4}$ wave-length $\therefore$ note of 4n as well (Doh another octave higher). And so on.

Note: The design of a stringed instrument determines the strength of each of the various overtones (or harmonics) and so determines the "quality" of the sound produced.

ORGAN PIPES.

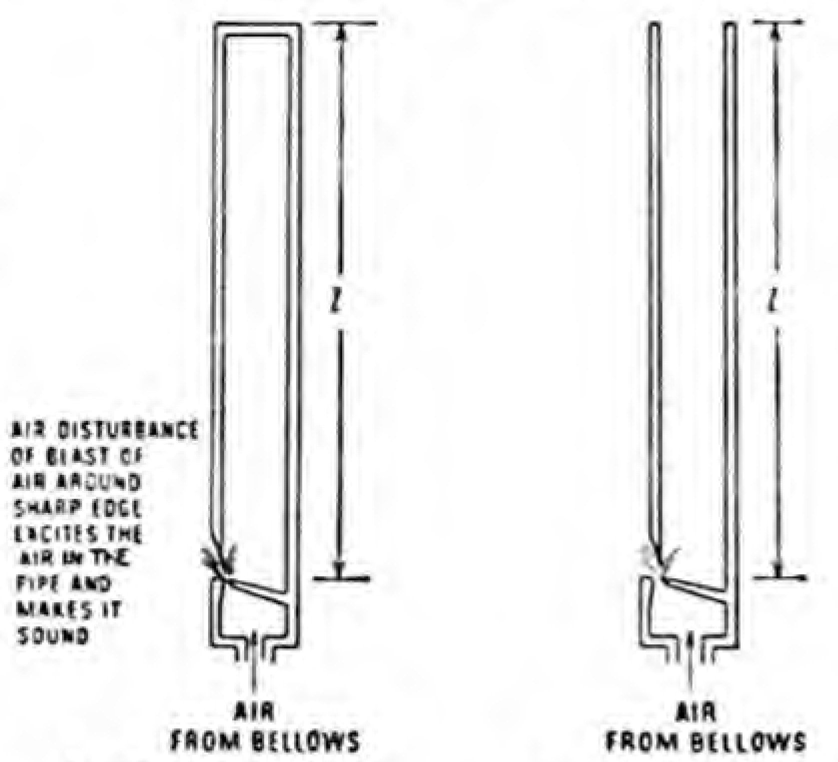
(a) *Closed organ pipes.* The wave-length of the note sounded, λ, $= 4 \times$ length of the pipe $= 4l$.

But $v = n\lambda$ (v = velocity of sound in air and n = frequency of note), so

$$n = \frac{v}{\lambda} = \frac{v}{4l} \therefore n = \frac{v}{4l}$$

Example: A closed organ pipe is 8 ft. in length. What note will it sound? Assume velocity of sound to be 1,024 ft. per sec.

$$n = \frac{v}{\lambda} = \frac{1{,}024}{4 \times 8} = \frac{1{,}024}{32} = 32.$$



A Closed Organ Pipe

An Open Organ Pipe

(b) *Open organ pipes.* The wave-length of the note sounded, λ, $= 2 \times$ length of the pipe $= 2l$.

But $v = n\lambda$

$$\text{so} \quad n = \frac{v}{\lambda} = \frac{v}{2l}$$

Example: Calculate the length of an open organ pipe designed to sound a note of frequency 224 c.p.s., assuming the velocity of sound to be 1,120 ft. per sec.

$$n = \frac{v}{2l}$$

$$\therefore 224 = \frac{1{,}120}{2 \times l}$$

$$\therefore 2l = \frac{1{,}120}{224} = 5$$

$$\therefore l = 2\tfrac{1}{2}\text{ ft.} = 2\text{ ft. }6\text{ in.}$$

The overtones of organ pipes. Open organ pipes emit all possible overtones, closed organ pipes emit only half as many; so a closed pipe and an open pipe, sounding the same note, have a very different quality.

BEAT NOTES. When two different notes are sounded together, the combined note is found to increase to a maximum intensity, die away to a minimum, rise again to a maximum and so on at a regular frequency. (Twin-engined aircraft often give this effect when their engines are not running at the same speed.)

For example, if notes of frequencies 500 and 499 c.p.s. are sounding simultaneously there will be one loud period (or beat) each second, because $500 - 499 = 1$. If the notes have frequencies of 250 and 250·5, there will be half a beat per second (i.e. 1 beat in 2 sec.) because $250{\cdot}5 - 250 = {\cdot}5$. *Number of beats per second = difference between frequencies in cycles per second.*

The döppler effect. The whistle of a locomotive rushing past a station platform falls suddenly in pitch as it passes. The same effect is noticed with the whine of a fast motor cycle or car. The frequency heard is greater than the real frequency as the sound approaches and lower than the real frequency as the source of sound recedes.

Let us consider an engine whistle of frequency 560 c.p.s. approaching at 60 m.p.h. (88 ft. per sec.). Imagine the engine is still, and we are moving towards it at 88 ft. per sec.—the effect is the same. If sound travels at 1,120 ft. per sec., the wave-length of the sound in air $= \frac{v}{n} = \frac{1{,}120}{560} = 2$ ft.

If we stand still, 560 of these waves pass us in a second $\therefore$ we hear the note of frequency 560.

But in moving 88 ft. towards the engine in a second we pass through 44 extra of these waves spaced 2 ft. apart, i.e. we receive $560 + 44$ in all $= 604$. We thus hear the note as 604 c.p.s. instead of 560 c.p.s. By similar reasoning, the note heard as the whistle goes away from us is $560 - 44 = 516$ c.p.s.

THE MEASUREMENT OF INTENSITY OR LOUDNESS OF SOUND. The human ear is a poor judge of loudness. Sounds are often measured in terms of the energy required to produce them. If there is an increase in intensity of 10 times, there is said to be a "gain of 1 'bel'". A smaller and more convenient unit is the "decibel", a tenth of a bel.

If there is a "gain of 1 decibel" in intensity, the sound is 1·259 times as loud as before. $(1{\cdot}259)^{10} = 10$. A gain of 5 decibels means an increase of $(1{\cdot}259)^5$ = approx. 3·2 times as loud, while a gain of 50 decibels means an increase of $(1{\cdot}259)^{50} = 10^5$ or 100,000 times as loud.

The decibel scale is thus a scale in which enormous differences in loudness can be expressed by means of small numbers.

The zero for the decibel scale of intensity is the faintest sound of frequency 1,000 c.p.s. which can be detected by the human ear.

The *phon* is a unit of loudness, as judged by the human ear. If a note (*of any frequency*) is judged by ear to be just as loud as one of 1,000 c.p.s. requiring x decibels of energy above zero intensity to produce it, the loudness of the note (or voice) is x phons.

Some examples (approximations):

0 phons—sound just too faint to be heard.
20 phons—a whisper.
30 phons—a watch 3 ft. away.
60 phons—ordinary conversation.
100 phons—pneumatic drill.
110 phons—"running up" an aero engine.
130 phons—sound so loud that it begins to hurt the ear.

THE SPEED OF GRAMOPHONE RECORDS. If the performance of an orchestra or singer is to be heard as it was recorded, the speed of the record in the home must be identical with that of the master record when the performance was recorded in the studio.

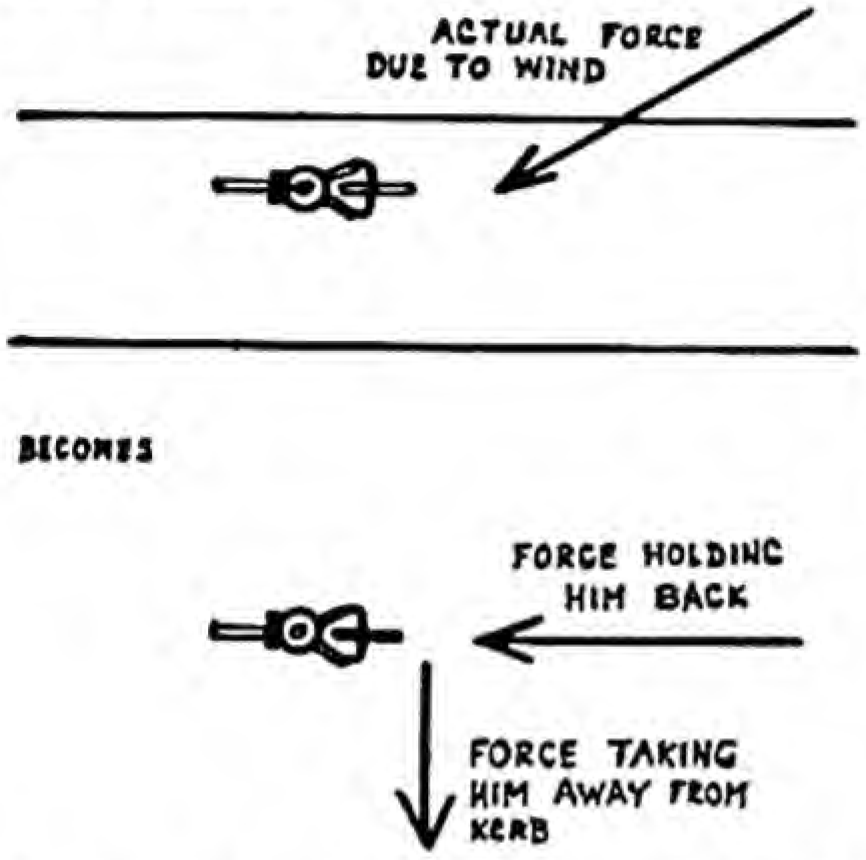
A record played at double the correct speed would give music a full octave too high.

The full range of speeds now in use is

78 r.p.m. standard records
45 r.p.m. }
$33\frac{1}{3}$ r.p.m. } long playing records
16 r.p.m. }

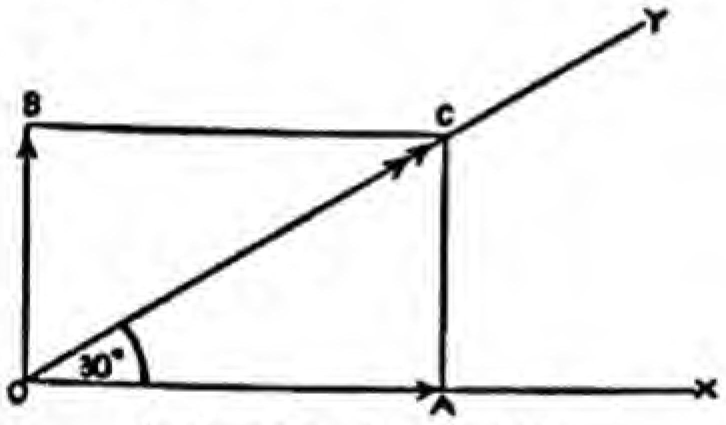
FORCES AND LAWS OF MECHANICS

THE RESOLUTION OF A FORCE INTO COMPONENT FORCES. It is often convenient to consider one force as two separate forces; for example, a wind diagonally across a road is best considered as exerting two distinct forces on a cyclist, one along the line of the road, holding him back, and one at right angles urging him away from the kerb.



Example: A man pushes a barrow with a force of 50 lb. up a slope of 30°. Resolve this force into vertical and horizontal components.

Construct a parallelogram with vertical and horizontal sides, of which the given force is the diagonal.



Scale: 1 inch = 40 lb.

Construction: OX is horizontal. Angle YOX is 30°. OC is made 1·25 in. long. CA is drawn vertical. CB is parallel to OA and OB to AC. OA represents the horizontal component, 43 lb. OB represents the vertical component, 25 lb.

THE RESULT OF THE ACTION OF MORE THAN ONE FORCE ON A BODY.

(a) *When the forces are parallel to each other the resultant is the sum of the various forces.*

Example 1: 10 lb. vertically downward, 5 lb. vertically downward.

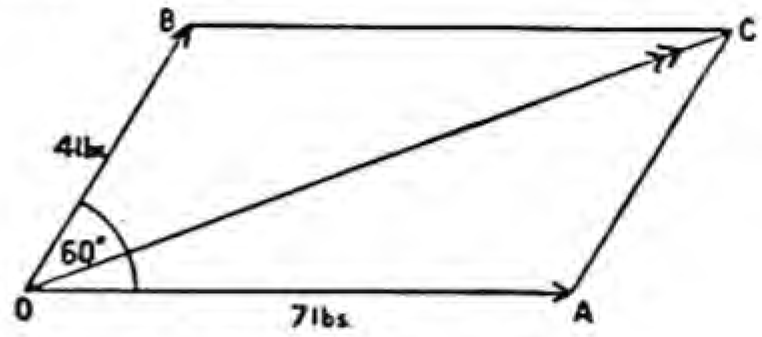
Resultant = 10 + 5 = 15 lb. vertically downward.

Example 2: 12 lb. vertically downward, 9 lb. vertically *upward.*

Resultant = 12 + (− 9) = 12 − 9 = 3 lb. vertically downward.

(b) *When the forces are not parallel. The parallelogram of forces is needed.*

Example 1:

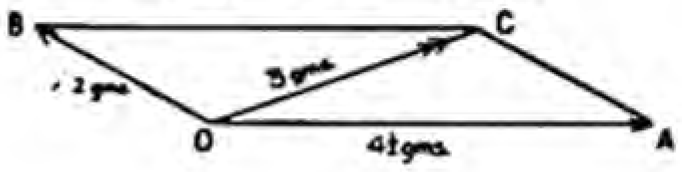


Scale: 1 cm. = 2 lb.

OA represents a horizontal force of 7 lb. OB represents a force of 4 lb. at an angle of 60° to the horizontal. The parallelogram is completed (OBCA). OC represents the "resultant" or the combined effect of the two forces. It is a force of 9·6 lb. acting in the direction OC.

Example 2:

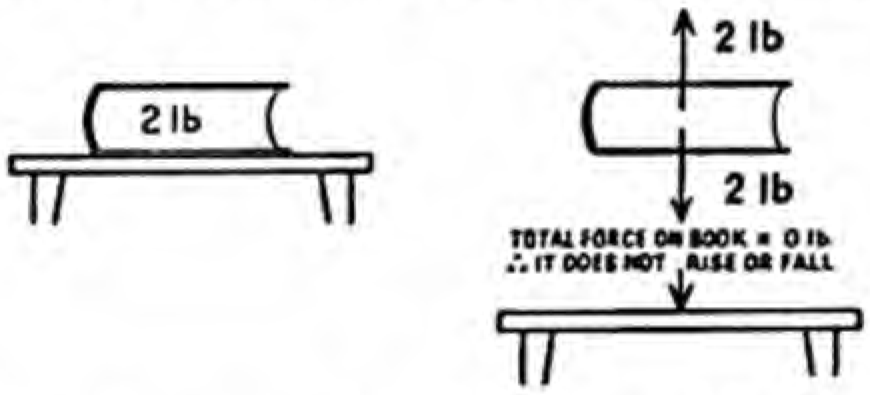
Scale: 1 in. = 4 gm.



ACTION AND REACTION

The force exerted by one body upon another is sometimes referred to as the "Action" of the body, e.g. a book, of weight 2 lb., has an "*action*" of 2 lb. on the table on which it rests. The table, however, reacts with an equal force upon the book, the "*Reaction*" of the table holding it still by counteracting the pull of gravity.

Action and Reaction are equal and opposite.



A force may be either a "push" or a "pull". We give the latter a special name—a "Tension".

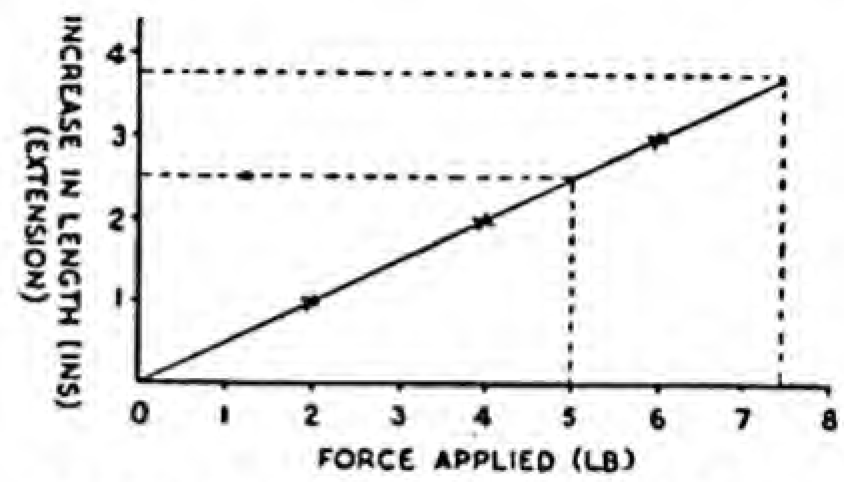
THE ACTION OF SPRINGS

HOOKE'S LAW. The extension of a spring is directly proportional to the force applied to it.

Example: A pull of 2 lb. extends a certain spring by 1 in., 4 lb. by 2 in., 6 lb. by 3 in. and so on. The force applied is often called the "stress", and the "give" of the spring the "strain". A more general way of stating Hooke's Law is, *strain is directly proportional to stress.*

Note: Hooke's Law is only true up to a certain point, known as the "elastic limit" of the material. When a force is applied to a spring and gradually increased, the extension of the spring goes up steadily with the increasing force. If the load is removed, the spring flies back at once to its original length.

A point is reached, however, when a slight increase in the load produces a very large increase in length, and the spring does not fly back at once when the load is removed. The spring has passed its "*elastic limit*", and is now useless.



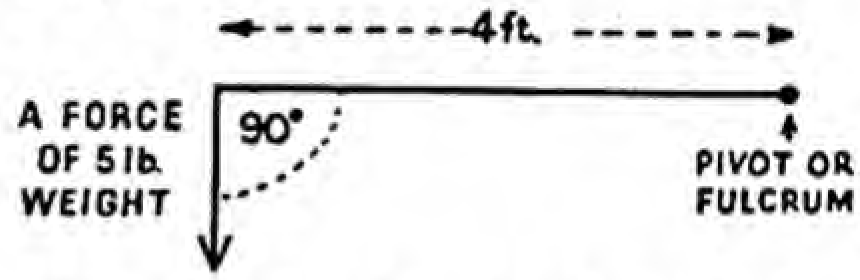
A graph illustrating Hooke's Law

Note: (1) A pull of 5 lb. stretches the string $2\frac{1}{2}$ in.

(2) When the spring is extended by $3\frac{3}{4}$ in., the force is $7\frac{1}{2}$ lb.

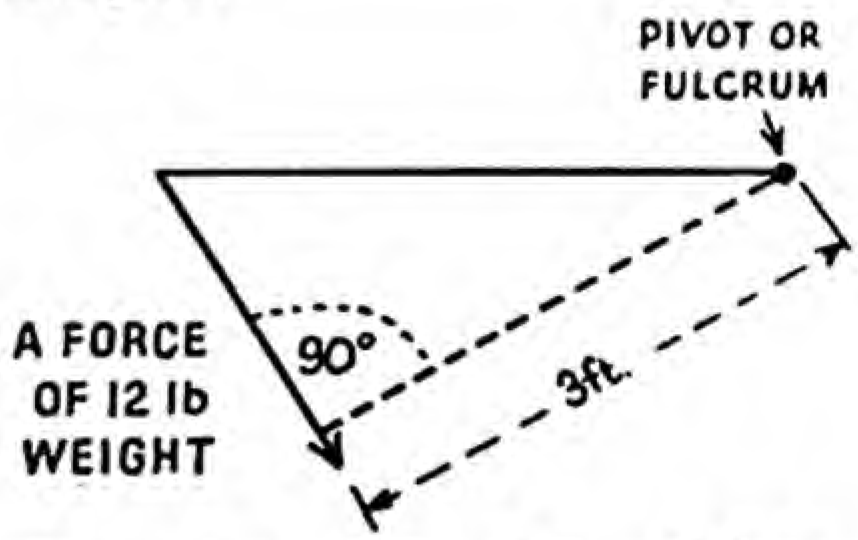
MOMENTS. The moment of a force is its turning effect about a particular point. It is measured by multiplying the size of the force by the *perpendicular* distance from the point (i.e. the distance measured at right angles to the force).

Example 1:



The moment = 5 lb. × 4 ft. = 20 lb. ft.

Example 2:

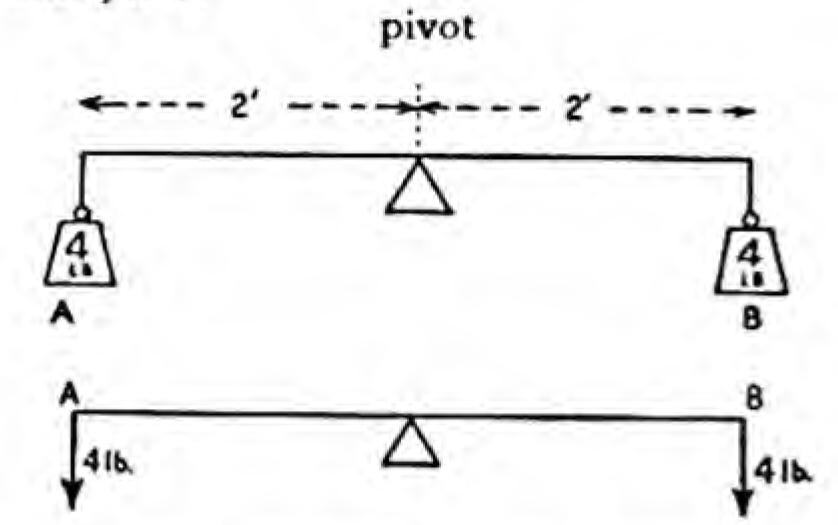


The moment = 12 lb. × 3 ft. = 36 lb. ft.

Moments can be "clockwise" ↻ or "anti-clockwise" ↺.

Several forces may act upon one body at the same time and yet the body may stay still or "be in equilibrium". In this case the sum of the clockwise moments must equal the sum of the anti-clockwise moments

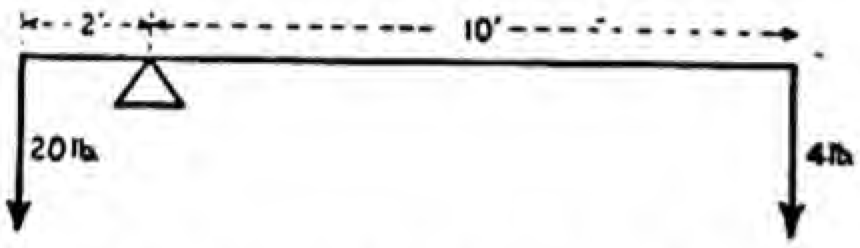
Example 1:



A causes the beam to swing in the direction opposite to that of the hands of a clock $\therefore$ it has an anticlockwise moment of 4 lb. $\times$ 2 ft. = 8 lb. ft.

B has a clockwise moment of 4 lb. $\times$ 2 ft. = 8 lb. ft. $\therefore$ the beam is in equilibrium—balanced.

Example 2:

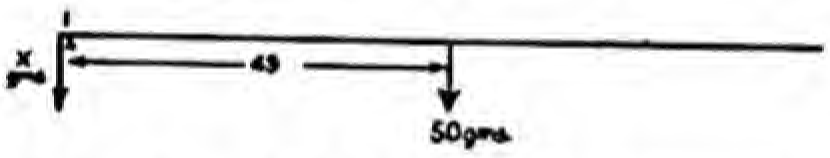


Clockwise moment = 4 lb. $\times$ 10 ft.
= 40 lb. ft.

Anticlockwise moment = 20 lb. $\times$ 2 ft.
= 40 lb. ft.

$\therefore$ equilibrium

Example 3: A 100 cm. rule has a hole drilled 1 cm. from the end and is hung up with string. It weighs 50 gm. What weight must be hung on the end to make it balance?



The weight of the ruler is reckoned as acting at its middle.

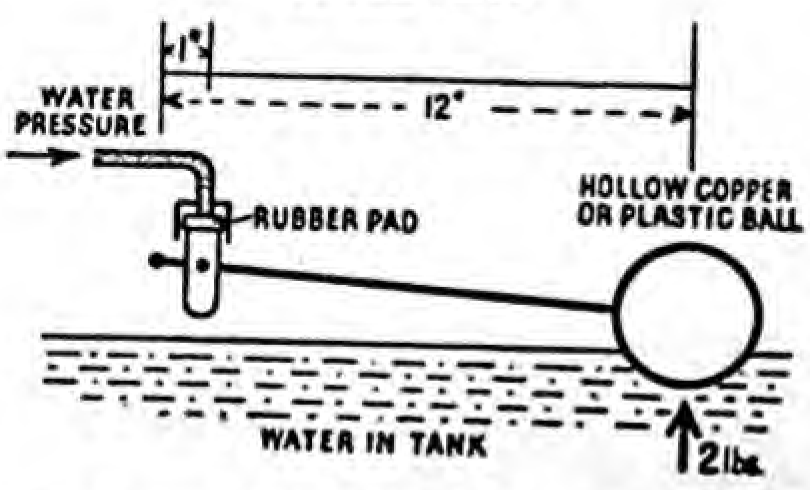
Clockwise moment = 50 gm. $\times$ 49 cm. = 2,450 gm. cm.

Anticlockwise moment = x gm. $\times$ 1 cm. = x gm. cm.

For balance, x = 2,450 gm.

Useful applications of the Law of Moments

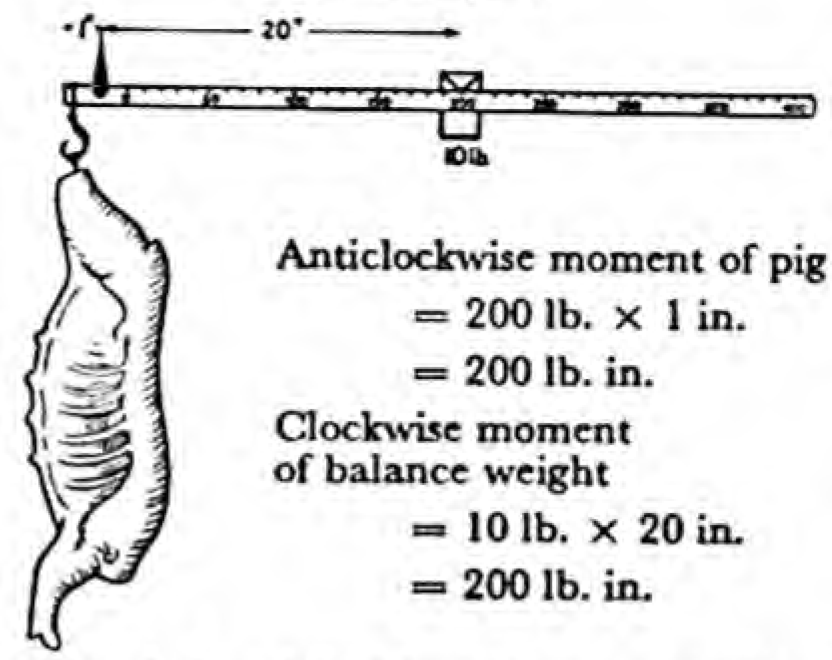
A ball valve



The water lifts the ball upward with a force of 2 lb.

The force on the rubber pad holding back the water supply is $\frac{12}{1} \times 2$ lb. = 24 lb.

The steel yard



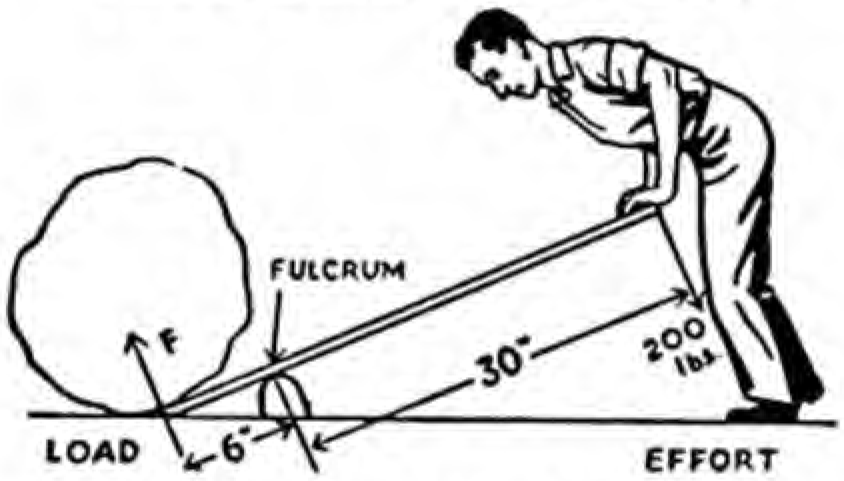
Anticlockwise moment of pig
= 200 lb. $\times$ 1 in.
= 200 lb. in.

Clockwise moment of balance weight
= 10 lb. $\times$ 20 in.
= 200 lb. in.

The pig is weighed by sliding a small steel weight along the steelyard, instead of using massive iron weights.

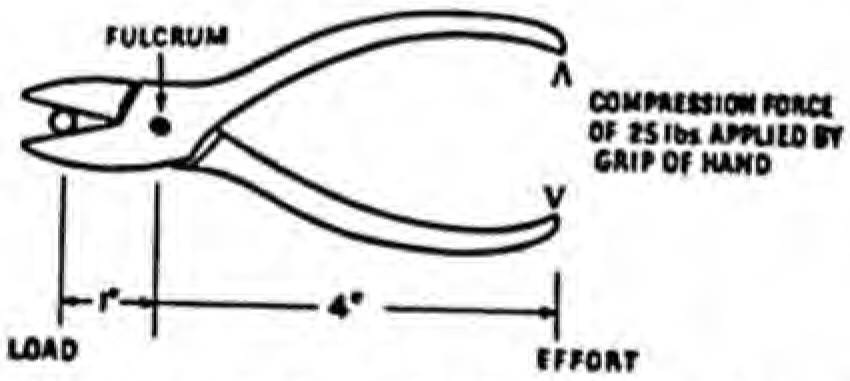
Calculations on a lever of the first type

Fulcrum between load and effort.



$$F \times 6 = 200 \times 30$$
$$F = 1000$$

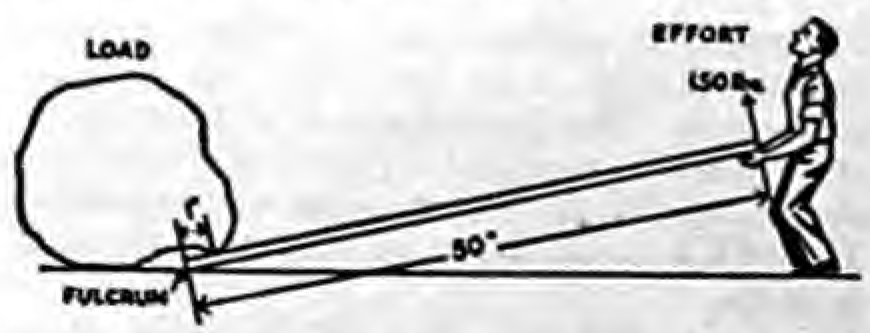
By means of this crowbar, the man, by exerting a force of 200 lb., is able to apply a force of 1,000 lb. to shift the stone.



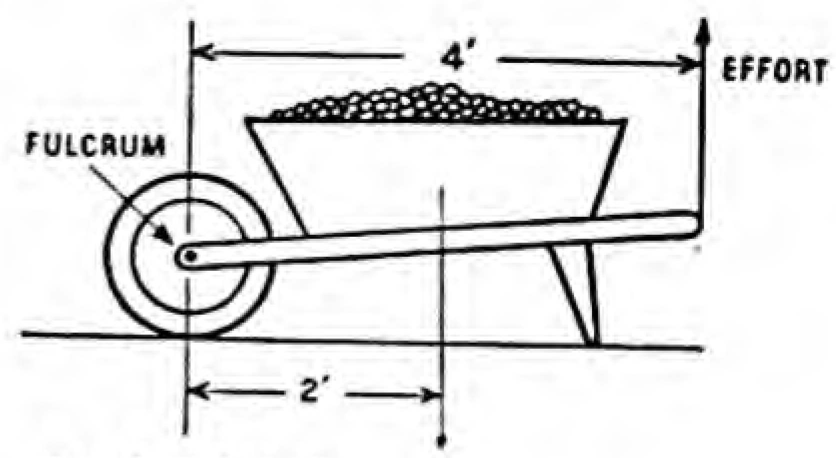
Force applied to wire by cutting edge of the pliers is 25 lb. $\times \frac{4 \text{ in.}}{1 \text{ in.}}$ = 100 lb.

Calculations on levers of the second type

Fulcrum at one end and effort at the other.



Force applied to rock = 150 lb. $\times \frac{50}{1}$
= 7,500 lb.

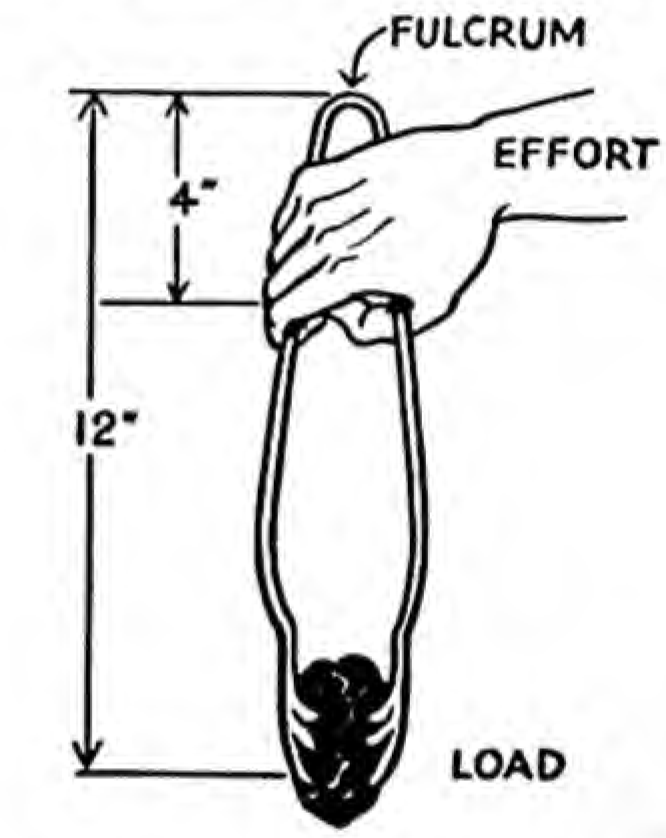


Load = 200 lb.
Reckoned to act at centre.

200 $\times$ 2 = Effort $\times$ 4.

$\therefore$ Effort = $\frac{200 \times 2}{4}$ = 100 lb.

A calculation on levers of the third type (with the fulcrum and the load at the ends).

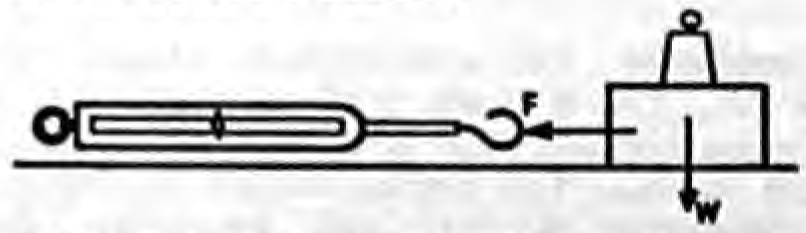


Grip of hand = a force of 15 lb.

Grip of claws on coal = $\frac{4}{12} \times 15$ lb.
= 5 lb.

Note that in this case it is *less* than the effort.

FRICTIONAL FORCES.



The spring balance is used to pull the wood block across the table, the necessary effort being read from the spring balance.

Results:

(1) Much force must be applied before the body moves. This force is equal and opposite to the *frictional force* between the block and the table, which adjusts itself just to equal the pull applied.

(2) A maximum reading of the balance is reached, at which the block moves steadily across the table. This is the *limiting friction* (F).

(3) The greater the weight applied to the block, the greater is the *limiting friction* (F).

(4) If F is divided by the total force between the two surfaces (W in this case), $\frac{F}{W}$ is always the same for the same surfaces.

$\frac{F}{W}$ = *coefficient of limiting friction.*

(5) Different surfaces have different coefficients of limiting friction. Oil smooths a surface and reduces the coefficient.

Calculation: It needs a horizontal force of 50 lb. to move a box weighing 112 lb. across a tiled floor. What force should be required to push back the empty box weighing 14 lb.?

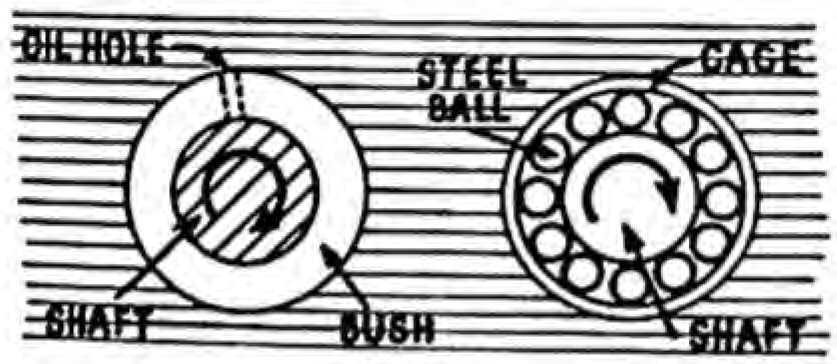
(Case 1) Coefficient of limiting friction $= \frac{50}{112}$

(Case 2) Coefficient of limiting friction $= \frac{P}{14}$

$$\therefore \frac{50}{112} = \frac{P}{14}$$

$$\therefore P = \frac{50 \times \overset{1}{\cancel{14}}}{\underset{8}{\cancel{112}}} = \frac{50}{8} = 6{\cdot}25 \text{ lb.}$$

A case in which friction is reduced to the minimum



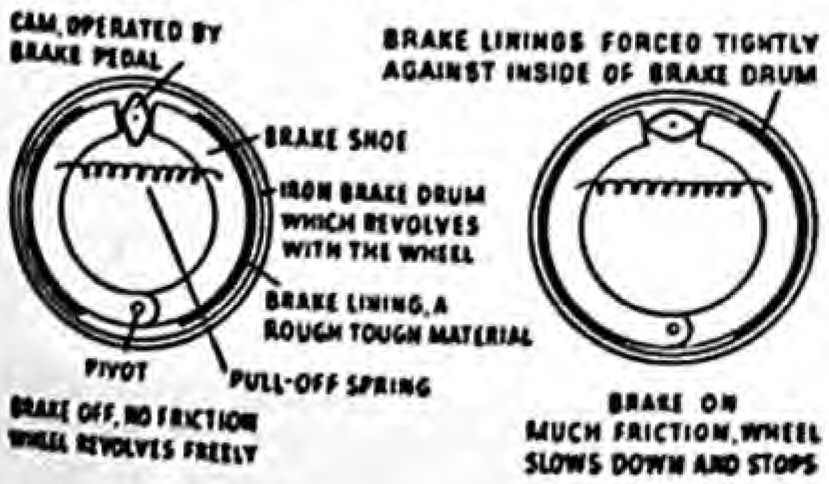
A plain bearing

A shaft revolves in a bush of a highly polished metal, say bronze. Oil reaches the surfaces through a hole drilled in the bush.

A ball bearing

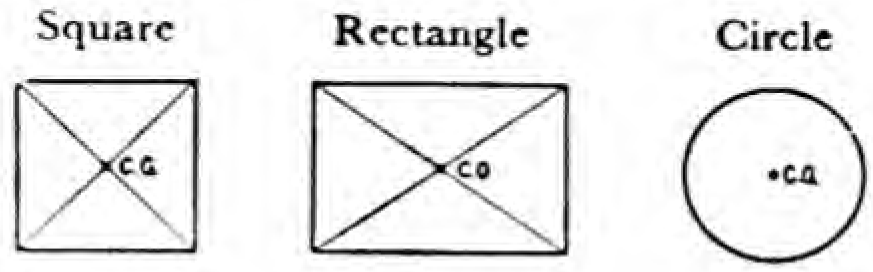
A shaft is supported by highly polished steel balls, contained in a cage. Ball bearings often run in a bath of oil.

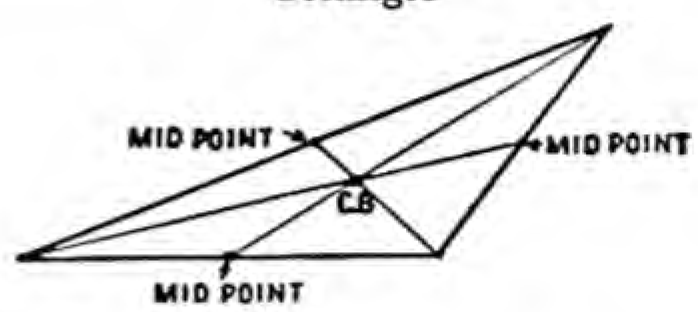
A case in which friction is increased to the maximum



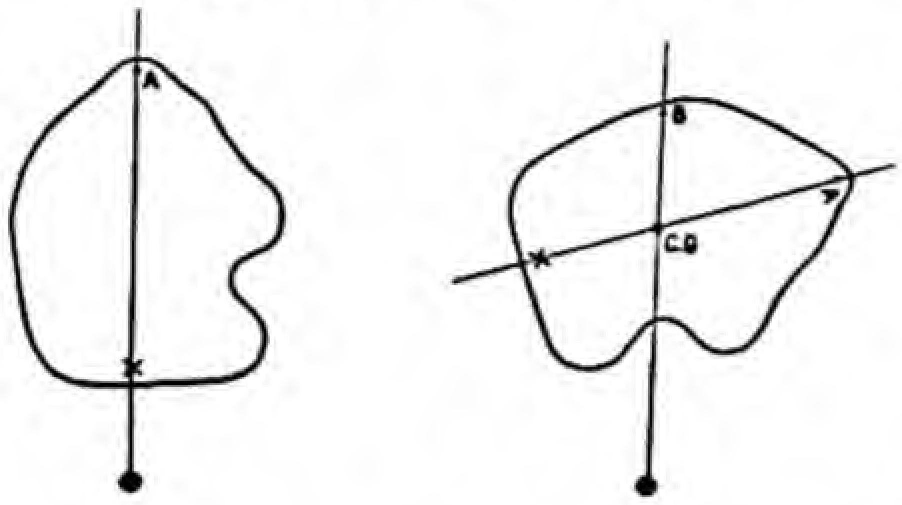
CENTRE OF GRAVITY. Although the weight is, in fact, distributed all over an object, it is convenient to consider that it is concentrated at one point, the *centre of gravity.* For regularly distributed weight (e.g. a rectangular block, a solid ball) the C.G. is at the centre. If it is possible to support a body at its C.G. (e.g. on a needle point) it will balance. When suspended on a string, the C.G. of the body is always vertically under the support.

Thin objects—e.g. sheet metal or cardboard shapes.





Experiment to find the C.G. of an irregular sheet of cardboard



Stage 1. Suspend by string from any point A, with plumb-line (vertical) in front. Mark position of plumb-line AX.

Stage 2. Suspend from any other point B. C.G. is where plumb-line crosses line AX, already marked in.

STABILITY

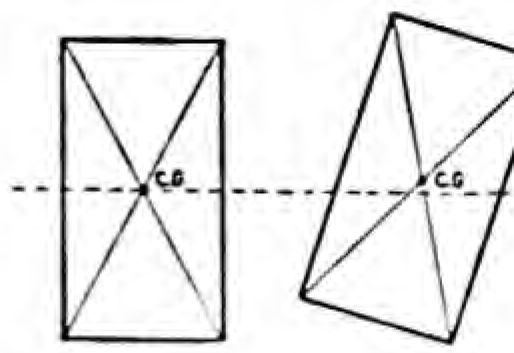
STABLE EQUILIBRIUM. A chair is in stable equilibrium because when it is tilted a little, and released, it moves back to the previous position.

UNSTABLE EQUILIBRIUM. A pencil balanced upon its point is in unstable equilibrium because a slight movement one way results in a much larger one in the same direction.

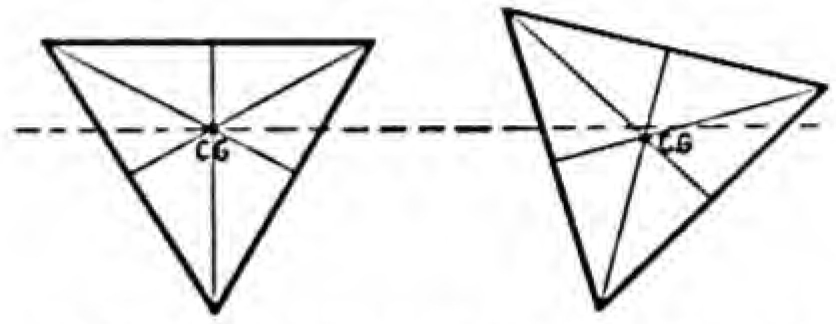
NEUTRAL EQUILIBRIUM. A billiard ball on a horizontal table is in neutral equilibrium, since, after a slight movement, it neither goes back nor goes further.

A demonstration with a plywood triangle

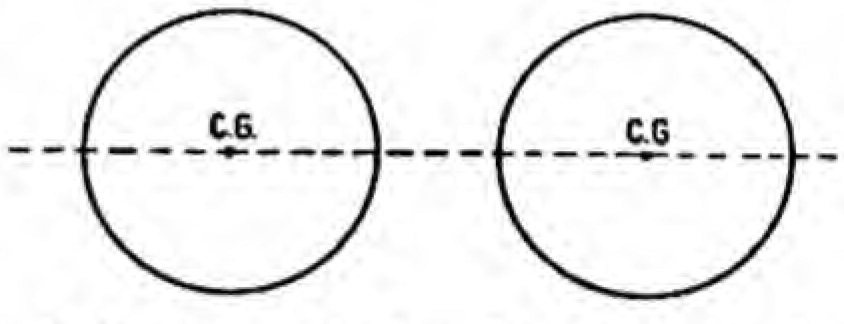
RELATIONSHIP BETWEEN CENTRE OF GRAVITY AND STABILITY. When a body is tilted, the position of the C.G. is changed. If it rises vertically, there is stable equilibrium. If it falls vertically, there is unstable equilibrium.



C.G. of tilted body is higher than before. ∴ it drops on release, restoring body to original position. ∴ *stable equilibrium.*

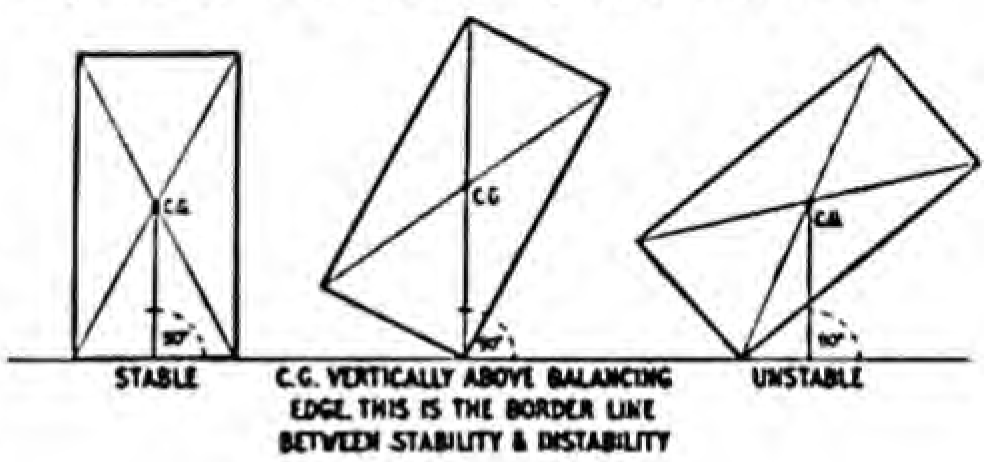


C.G. of tilted body is lower than before. ∴ when it drops still further, on release, the movement is in the same direction. ∴ *unstable equilibrium.*

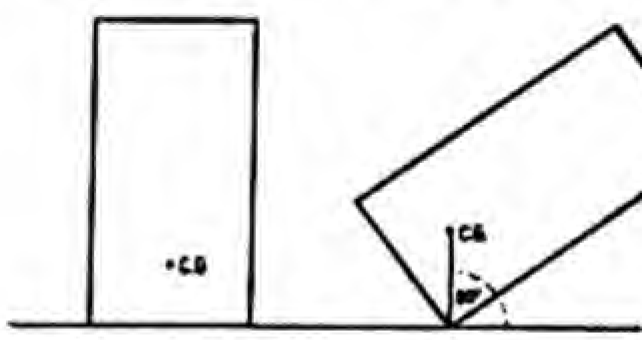


C.G. neither raised nor lowered by moving billiard ball. ∴ *neutral equilibrium.*

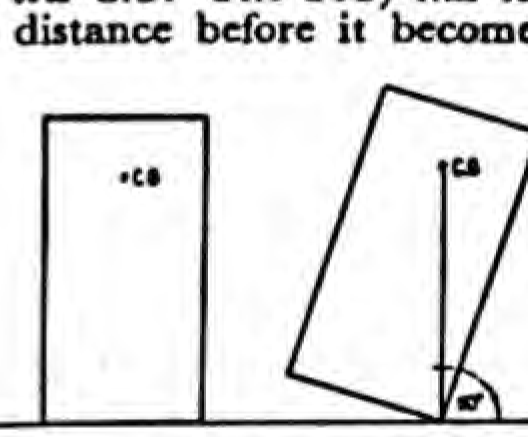
The C.G. of a body in stable equilibrium is vertically over the base



A low C.G. makes for stability.

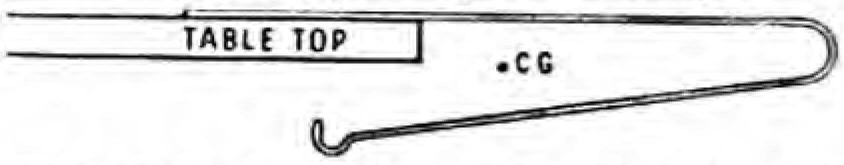


(1) *Heavy weights kept to bottom of structure, giving low C.G.* The body has to tilt a very great distance before it becomes unstable.

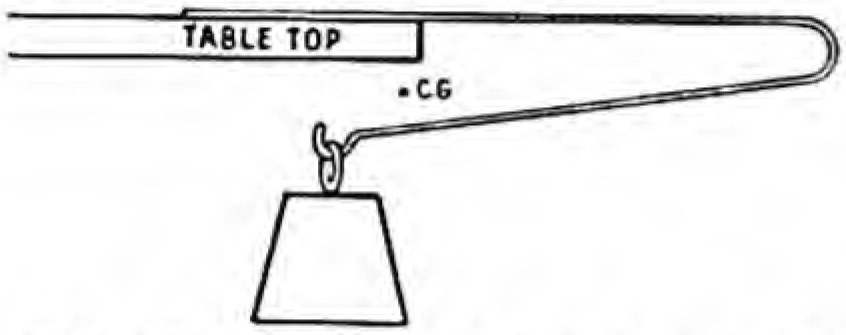


(2) *Heavy weights concentrated near top of structure, giving high C.G.* The body needs very little tilt before it becomes unstable.

An amusing example of stability.



(1) This hook, made of stiff wire, falls off as soon as it is released. The C.G. is not vertically below the supporting body.
(2) The same hook, carrying a heavy weight, no longer falls when released.



The C.G. of the combined weight and hook is near to the weight, and under the table which is supporting the hook. The hook no longer topples, although it carries much more weight than before.

EXAMPLES OF LOW CENTRE OF GRAVITY FOR SAFETY

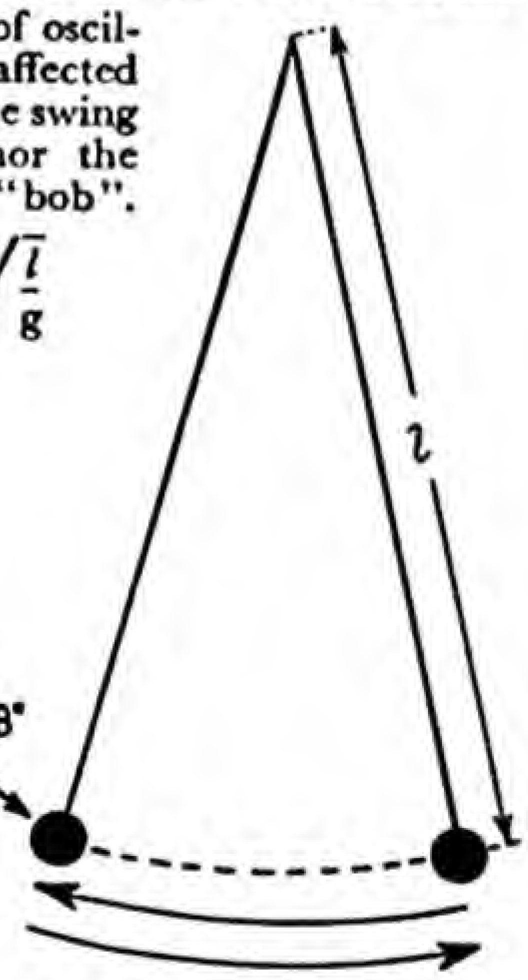
(1) A racing car is built low to the ground.
(2) Passengers are not allowed to stand on top of a bus.
(3) It is foolish for several people in a rowing boat to stand up at the same time.

THE PENDULUM. The pendulum consists of a heavy weight supported by a light string or rod. This is another example of stable equilibrium.

THE LAWS OF THE PENDULUM.

(1) The time of oscillation is not affected by the size of the swing (amplitude), nor the weight of the "bob".

(2) $T = 2\pi\sqrt{\frac{l}{g}}$



If T is in seconds, l in feet, g = 32.

T = time to complete a whole swing, i.e. *there and back.*

Example 1: A pendulum is 2 feet long. What is its time of oscillation, (T)?

$$T = 2\pi\sqrt{\frac{2}{32}} = 2\pi\sqrt{\frac{1}{16}} = 2\pi \times \frac{1}{4}$$

$$= \frac{\pi}{2} = \frac{22}{7 \times 2} = \frac{11}{7}$$

Time = $1\frac{4}{7}$ seconds.

Example 2: A grandfather clock has a pendulum which swings from one side to the other in 1 second. What is its length?

$$T = 2 \text{ seconds.} \quad T = 2\pi\sqrt{\frac{l}{32}}$$

$$2 = \frac{2 \times 22}{7}\sqrt{\frac{l}{32}} \quad \therefore \frac{7}{44} \times 2 = \sqrt{\frac{l}{32}}$$

$$\therefore \frac{7}{22} = \sqrt{\frac{l}{32}}$$

$$\therefore \frac{7^2}{22^2} = \left(\sqrt{\frac{l}{32}}\right)^2 = \frac{l}{32}$$

$$\therefore \frac{49}{484} = \frac{l}{32}$$

$$\therefore l = \frac{49 \times \overset{8}{\cancel{32}}}{\underset{121}{\cancel{484}}} = 3{\cdot}24 \text{ ft.} = 3 \text{ ft. } 3 \text{ in. approx.}$$

MACHINES. A machine is a contrivance for overcoming a resistance at one point by the application of a force at another. The force applied (P) is known as the *Effort.* The resistance overcome (L) is the *Load.*

The lever is a very simple type of machine.

The Mechanical Advantage of a Machine (M.A.)

$$= \frac{\text{Load}}{\text{Effort}} = \frac{L}{P}$$

Note: This depends very much upon the condition of the machine, lubrication, etc.

The Velocity Ratio of a Machine (V.R.)

$$= \frac{\text{distance moved by Effort}}{\text{distance moved by Load}}$$

Note: This depends entirely on the geometry of the machine—a well-kept and lubricated machine has exactly the same velocity ratio as one neglected, rusted and stiff.

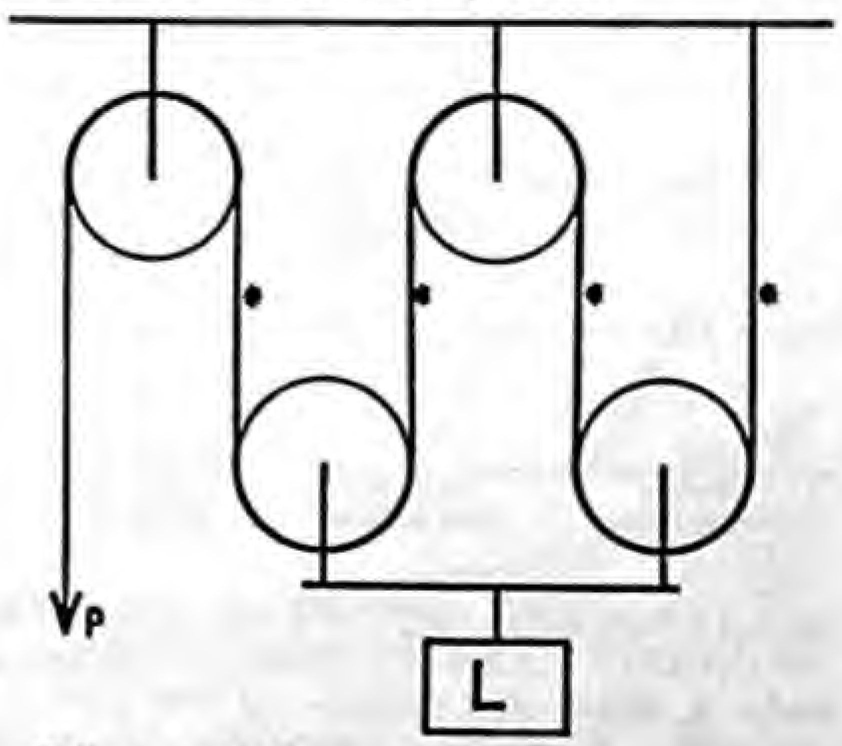
The Efficiency of a Machine

$$= \frac{\text{Energy obtained from machine}}{\text{Energy supplied to machine}}$$

$$= \frac{\text{Mechanical advantage}}{\text{Velocity ratio}}$$

N.B.: Efficiency can never exceed 1, or 100%.

Example 1: **A pulley system.**



Effort = Pull on rope (P).
Load = Weight to be raised (L).

To find velocity ratio. Suppose L to be lifted vertically upward 1 ft. There will be 1 ft. of slack in each of the ropes marked •; to pull up the slack, P must move 4 ft.

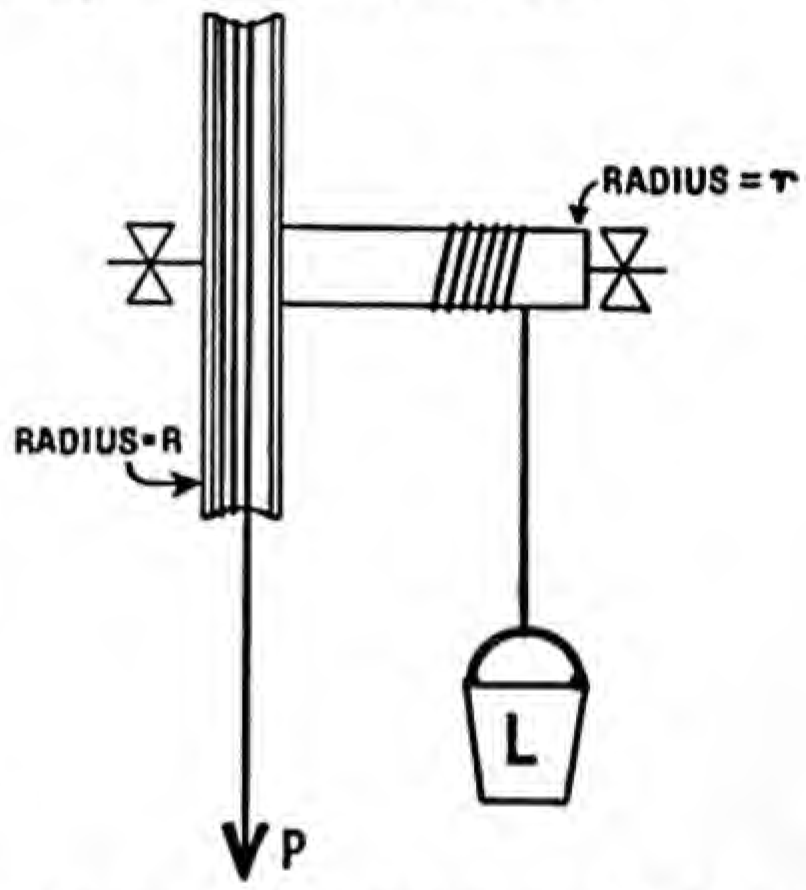
$$\therefore \text{Velocity ratio} = \frac{4}{1} = 4.$$

Suppose L = 100 lb. and P = 40 lb.

$$\text{Mechanical advantage} = \frac{L}{P} = \frac{100}{40} = \frac{10}{4} = 2{\cdot}5.$$

$$\text{Efficiency} = \frac{\text{M.A.}}{\text{V.R.}} = \frac{2{\cdot}5}{4} = {\cdot}625 \text{ or } 62{\cdot}5\%.$$

Example 2: **A wheel and axle.**



Consider one complete turn of the wheel and axle. The wheel will wind off a length of rope equal to its circumference, $2\pi R$. $\therefore$ P moves $2\pi R$.

The axle will wind up a length of rope equal to its circumference, $2\pi r$ $\therefore$ L moves $2\pi r$

$$\therefore \text{V.R.} = \frac{2\pi R}{2\pi r} = \frac{R}{r}.$$

Suppose R = 20 and r = 4

$$\therefore \text{V.R.} = \frac{20}{4} = 5.$$

Suppose L = 50 lb. and P = 20 lb.

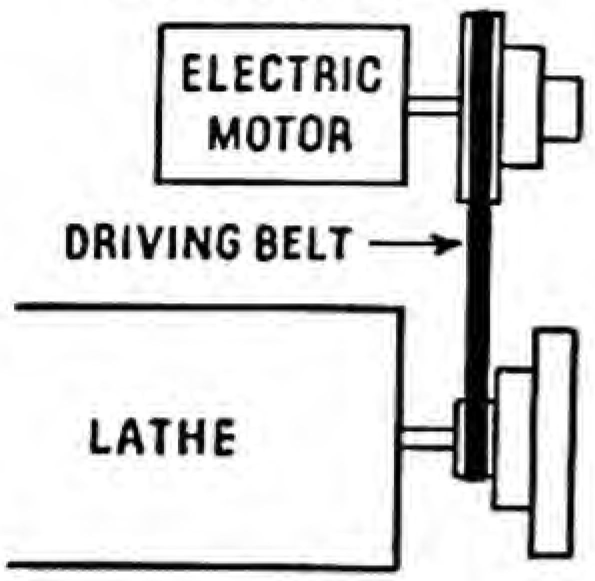
$$\text{Mechanical advantage} = \frac{50}{20} = 2{\cdot}5.$$

$$\text{Efficiency} = \frac{\text{Mechanical advantage}}{\text{Velocity ratio}} = \frac{2{\cdot}5}{5} = {\cdot}5 = 50\%.$$

Note: Although, in general, high efficiencies are aimed at, because less energy is wasted in working the machine, an efficiency of less than 50% is sometimes regarded as an advantage in a particular case. Consider, for example, a pulley system, which is highly efficient. Immediately the hands are taken from the rope, the load being raised takes control, begins to fall and causes the pulleys to run in the reverse direction. If the efficiency is less than 50% the weight itself cannot exert enough force to work the machine, so it hangs stationary when the operator releases the rope on which he is pulling.

Example 3: **A machine with a variable velocity ratio.**

A belt-driven lathe.



Suppose the radii of the pulleys are 2 in., 3 in. and 4 in. With the belt as shown, the velocity ratio is $\frac{2}{4} = \frac{1}{2}$.

With the belt in the middle position, the velocity ratio is $\frac{3}{3} = 1$.

In the outside position, the V.R. $= \frac{4}{2} = 2$.

The same idea is used (with a different method of achieving it) in the gear-box of a motor car, which usually has three or four different ratios, plus one extra, for going backwards.

Example 4: **Chain wheels and sprockets on a cycle.**

The chain-wheel is turned by the pedals, pulling round with it an endless chain which passes over the rear sprocket which in turn drives the rear wheel.

Chain-wheels can be bought with from 40 to 54 teeth, and sprockets with from 14 to 22.

For very high speeds on a level racing track, a very powerful rider might choose a 14-tooth sprocket and a 54-tooth chain-wheel.

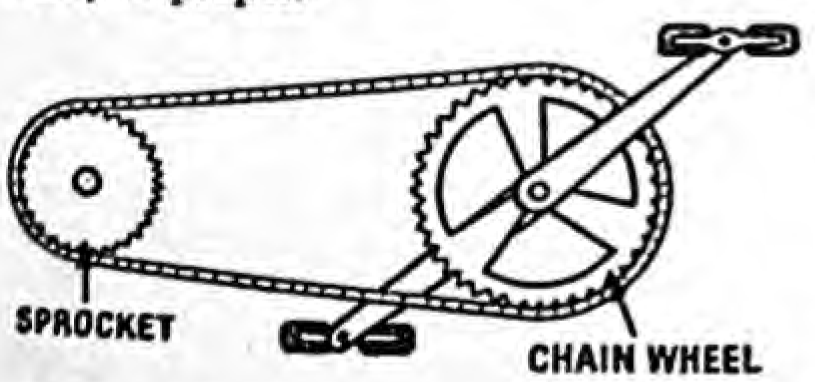
$$\text{Velocity ratio} = \frac{14}{54} = \frac{1}{3{\cdot}9}$$

(the back wheel goes round almost four times as fast as the pedals).

For a young child or invalid, we might go to the other extreme, a 22-tooth sprocket driven by a 40-tooth chain-wheel.

$$\text{V.R.} = \frac{22}{40} = \frac{1}{1{\cdot}8}$$

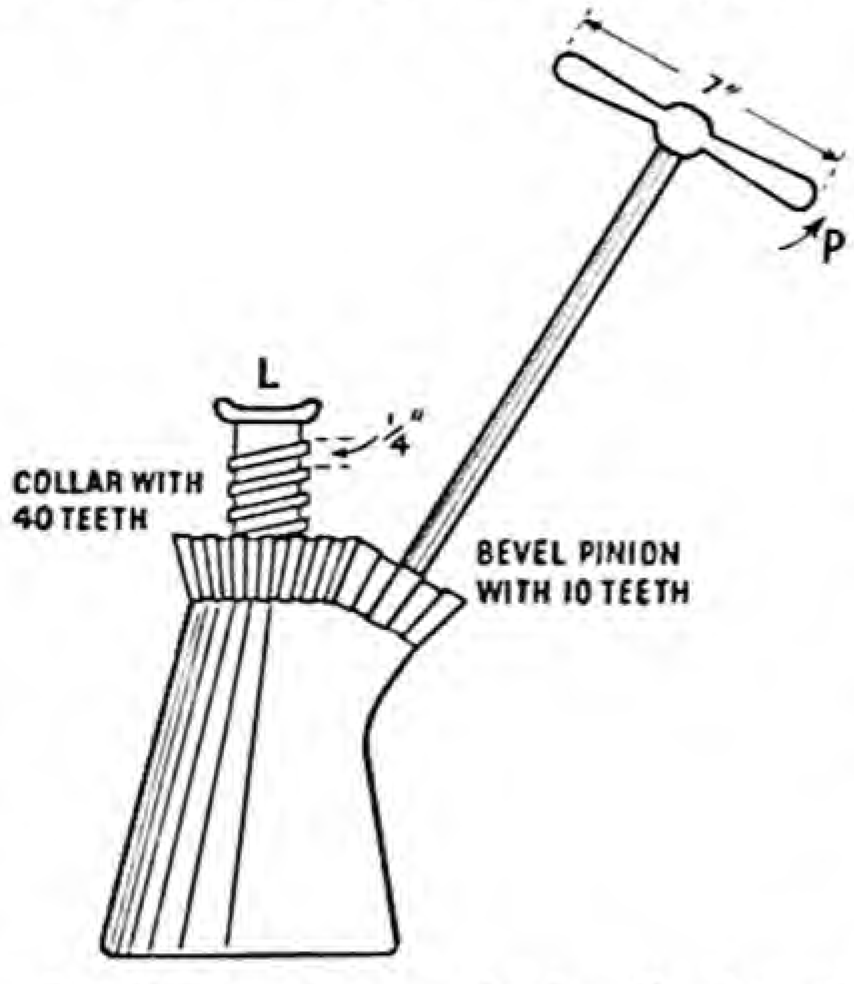
This will be a very slow bicycle, but will be easy to propel.



Many cycles have a 3-speed gear, which gives, in addition to the normal velocity ratio, a specially high one ("low gear") for climbing hills, and a specially low one ("high gear") for going fast on the level or downhill.

The three-speed hub commonly employed multiplies the normal velocity ratio by $\frac{4}{3}$ for low gear and divides it by $\frac{4}{3}$ for high gear.

Example 5: **A car-jack—a screw-jack.**



Let the hands turn the handle through one complete revolution. Assuming hands are pressing on the ends of the handle, distance moved by effort $= \pi \times$ diameter $= \frac{22}{7} \times 7$ in. $= 22$ in.

The bevel pinion makes one complete revolution too, its 10 teeth passing through 10 of the 40 teeth of the collar and so turning it $\frac{10}{40}$ turns $= \frac{1}{4}$ turn.

When the collar makes one complete turn it lifts the load by the "pitch" of the screw, $\frac{1}{4}$ in. In $\frac{1}{4}$ turn, it lifts it $\frac{1}{4}$ of $\frac{1}{4}$ in. $= \frac{1}{16}$ in.

Velocity ratio $= 22$ in. $\div \frac{1}{16}$ in. $= 22 \times 16$
$= 352$.

It is found that a force of 8 lb. applied to the end of the handle of the jack will raise a load of 1,056 lb. The Mechanical Advantage $= \frac{1{,}056}{8} = 132$.

$$\therefore \text{Efficiency} = \frac{\text{M.A.}}{\text{V.R.}} = \frac{132}{352} = \frac{3}{8} = 37{\cdot}5\%$$

WORK DONE BY A FORCE = force exerted $\times$ distance moved in the direction of the force.

Example 1: A 7-lb. weight is lifted from the floor on to a table 3 ft. high. How much work has been done?

Work = Force $\times$ Distance = P $\times$ S
= 7 lb. $\times$ 3 ft. = 21 ft.-lb.

Example 2: A 15-stone man climbs a flight of stairs to a room 40 ft. above ground level. How much work does he do?

15 stone = 15 $\times$ 14 = 210 lb.

Work = P $\times$ S = 210 $\times$ 40 = 8,400 ft.-lb.

(Calculations such as this explain why heavy people with heart trouble are advised to sleep downstairs.)

Example 3: A locomotive, exerting a force of 1,000 lb., pulls a train 1 mile along a level track. How much work has been done?

Work = P $\times$ S = 1,000 lb. $\times$ 5,280 ft.
= 5,280,000 ft.-lb.

The unit of work is the foot-pound—the work done when a force of 1 lb. weight moves 1 ft. in the direction of the force.

There is another unit, the erg, which is the work done when a force of 1 dyne (1 gm. wt. $\div$ 981) moves 1 centimetre in the direction of the force.

POWER is the rate at which work is done. E.g. if 1,000 ft.-lb. of work are done in 4 sec., the power of the machine is 250 foot-pounds per second.

1 Horse-power = 550 ft. lb. per second.

Example: A car engine is developing 20 horse-power and is driving the car at 30 m.p.h. What force is being applied to the road to propel the car?

20 horse-power = 20 $\times$ 550 ft.-lb. per sec.
= 11,000 ft.-lb. per sec.

30 m.p.h. = 44 ft. per sec.

In 1 second, force P moves 44 ft. and does 11,000 ft.-lb. of work.

Work = P $\times$ S
$\therefore$ 11,000 = P $\times$ 44

$$\therefore \text{P} = \frac{11{,}000}{44} = \frac{1{,}000}{4} = 250.$$

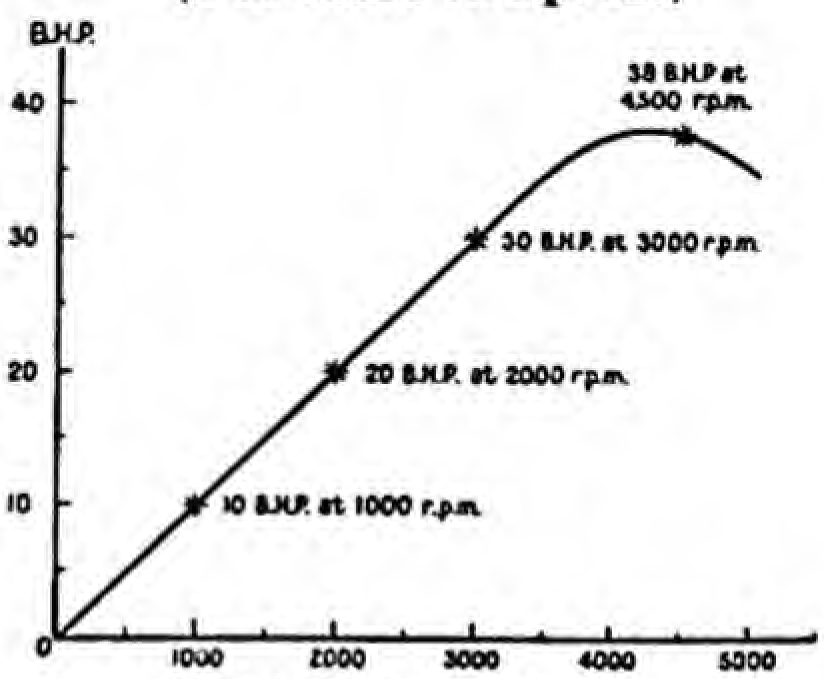
The force is 250 lb.

BRAKE HORSE-POWER (B.H.P.) is the actual power output of the engine. The name is derived from one method of measuring power, in which the engine is made to drive a wheel against a measured braking force.

INDICATED HORSE-POWER (I.H.P.). This is the horse-power calculated for a machine from a knowledge of its design and size, as well as the energy it receives in the form of fuel. It is always very much greater than the B.H.P. because even the best engines waste most of the energy given to them, giving out large quantities of unwanted heat. (Hence the need for a car radiator.)

$$\text{Efficiency of an engine} = \frac{\text{B.H.P.}}{\text{I.H.P.}}$$

The B.H.P. graph of a car engine (a so-called 10-h.p. car)



Revolutions per minute.

Note how it is necessary to keep the engine running fast in order to develop maximum power—hence the need for a variable gear-box. Also, the graph explains why it is so easy for an inexperienced driver to stop his engine when starting from a standstill. There is hardly any power when the engine is running slowly.

ELECTRICAL UNITS OF POWER—the watt and kilowatt.

1 **horse-power** is equivalent to 746 watts or ·746 kilowatts.

Example 1: An electric motor has an efficiency of 95% and requires a power of 3 kilowatts. What horse-power will it deliver?
3 kilowatts = 3,000 watts.
Efficiency = 95%. ∴ output = 95% of 3,000 watts = 2,850 watts.

But 746 watts are equivalent to 1 horse-power, ∴ 2,850 watts are equivalent to $\frac{2{,}850}{746}$ h.p. = 3·8 h.p.

Example 2: An electric motor is employed to drive a machine needing a power of 2 h.p. If the motor is 80% efficient, what electrical power will it need?

2 h.p. = 2 × 746 watts = 1,492 watts.

The motor is only 80% efficient, so it will need $\frac{100}{80}$ × 1,492 watts to drive it = 1,865 watts.

Example 3: An electric motor delivers 5 horse-power and is driven by 4,103 watts. Calculate its efficiency.

$$\text{Efficiency} = \frac{\text{output power}}{\text{input power}} = \frac{5 \text{ h.p.}}{4{,}103 \text{ watts}}$$
$$= \frac{5 \times 746 \text{ watts}}{4{,}103 \text{ watts}} = \frac{3{,}730}{4{,}103}$$
$$= \frac{10}{11} = 90{\cdot}9\%.$$

THE MECHANICAL EQUIVALENT OF HEAT. 778 ft.-lb. of work must be done in order to produce 1 B.Th.U. of heat.
Example: A waterfall is 389 feet high. Assuming that all the energy of the falling water is converted to heat, how would the temperatures of the water at the top and bottom of the waterfall compare?

Consider 1 lb. of water. It moves 389 ft. in the direction of the force of 1 lb. causing it to fall, ∴ work done = P × S = 1 × 389 = 389 ft.-lb.

This is equivalent to $\frac{389}{778}$ B.Th.U. = ½ B.Th.U. This quantity of heat raises the temperature of 1 lb. of water through ½°F.

POTENTIAL ENERGY. This is the energy stored in a body by virtue of its position.
Example: To wind a grandfather clock, a weight of 20 lb. is raised through 3 ft. vertically. To do this, 20 lb. × 3 ft. = 60 ft.-lb. of work has to be done. This energy is stored up in the weight and given out, little by little, during the coming week, to drive the clockwork. When the weight reaches the floor, the Potential Energy is nil, so the clock stops.

KINETIC ENERGY. This is the energy a body possesses because of its motion. K.E. = $\frac{Mv^2}{64}$ where K.E. is in ft.-lb., M is mass in pounds and v is its speed in ft. per sec.
Example 1: What is the effect upon Kinetic Energy: (a) of doubling the mass of the moving body; (b) of making the speed five times as great.

(a) K.E. is proportional to Mass; ∴ when Mass is doubled, so is K.E.
(b) K.E. is proportional to v^2—the square of the speed; ∴ when speed is 5 times, K.E. is 5^2 or 25 times.

Example 2: Calculate the Kinetic Energy of a bullet weighing ·05 lb. and travelling at 1,000 ft. per sec.

$$\text{K.E.} = \frac{Mv^2}{64} = \frac{{\cdot}05 \times 1{,}000 \times 1{,}000}{64}$$
$$= 781{\cdot}25 \text{ ft.-lb.}$$

THE RELATIONSHIP BETWEEN POTENTIAL AND KINETIC ENERGY. When a body falls from a height it loses Potential Energy and gains Kinetic Energy. The loss in P.E. is exactly balanced by the gain in K.E., i.e. P.E. + K.E. of a certain body remains constant.

A weight, about to drop, has maximum P.E. and no K.E. At the instant of striking the ground, it has maximum K.E. and no P.E.
Note: When the body strikes the ground, the Kinetic Energy cannot disappear—it is converted into other forms, e.g. heat, sound, or it does mechanical work, like making a crater.

MOVEMENT

SPEED or VELOCITY is the rate of change of position. If a body changes its position rapidly it has a large speed. Units: miles per hour, feet per sec., cm. per sec.

ACCELERATION is the rate of change of velocity.

Example: A car changes its speed from 30 m.p.h. to 60 m.p.h. in 2 minutes.

$$\text{Acceleration} = \frac{60 - 30 \text{ m.p.h.}}{2 \text{ minutes}} = \frac{30 \text{ m.p.h.}}{2 \text{ min.}}$$
$$= 15 \text{ miles per hour per min.}$$

Units: Miles per hour per hour; feet per sec. per sec.; cm. per sec. per sec.
Note: When a body slows down, it has a negative acceleration; e.g. −5 ft. per sec. per sec.

RETARDATION is negative acceleration; e.g. an acceleration of −5 ft. per sec. per sec. is a retardation of + 5 ft. per sec. per sec.

Formulae: u = initial velocity
v = final velocity
a = acceleration
S = distance covered
t = time taken.

Units: All units must "match"; e.g.
u and v in miles per hour
a in miles per hour per hour
S in miles
t in hours

It is assumed that the acceleration is constant.

Equation 1: S = **average speed** × t
$$= \frac{u + v}{2} \times t.$$

Equation 2: $v = u + at.$
Equation 3: $S = ut + \frac{1}{2}at^2.$
Equation 4: $v^2 = u^2 + 2aS.$

Note: It is useful to remember that 60 m.p.h. = 88 ft. per sec.

Example (a): A car averaged 95 m.p.h. in a 24-hour road race. How far did it travel?
Eqn. 1: S = average speed × t
= 95 m.p.h. × 24 hours
= 2,280 miles.

Example (b): A car takes 20 seconds to reach 60 m.p.h. from a standing start. Find the acceleration.
Eqn. 2: v = u + at
u = 0
v = 60 m.p.h. = 88 ft per sec.
t = 20 secs.
∴ 88 = 0 + (a × 20)
∴ 88 = 20a
∴ $a = \frac{88}{20} = 4{\cdot}4$

The acceleration is 4·4 ft. per sec. per sec.

Example (c): A goods train has reached the speed of 30 m.p.h. 5½ miles after leaving its starting point. Find the acceleration.
u = 0; v = 30 m.p.h. = 44 ft. per sec.; S = 5½ miles.
Eqn. 4: $v^2 = u^2 + 2aS$
$44^2 = 0^2 + 2 \times a \times (5\frac{1}{2} \times 5{,}280)$
$44 \times 44 = 0 + 2a \times 29{,}040$

$$a = \frac{\overset{4}{\cancel{44}} \times \overset{4}{\cancel{44}}}{2 \times \cancel{29{,}040}} = \frac{1}{30} \text{ ft. per sec. per sec.}$$
$\cancel{2{,}640}$
$\cancel{240}$
$\cancel{60}$
15

Example (d): A car travelling at 60 m.p.h. on a dry road should be able to stop in 60 yards in an emergency. Calculate the retardation caused by the brakes.

A 10-lb. weight is taken to a height of 144 feet and dropped. Here is its story before hitting the ground.

Time after dropping	*Height (h)*	*P.E. = M × h*	*Speed*	*KE = $\frac{Mv^2}{64}$*	*P.E. + K.E. ft. lb.*
0 sec.	144 ft.	1,440 ft. lb.	0	0	1,440 + 0 = 1,440
1 sec.	128 ft.	1280 ft. lb.	32 ft. per sec.	$\frac{10 \times 32 \times 32}{64}$ = 160 ft. lb.	1,280 + 160 = 1,440
2 sec.	80 ft.	800 ft. lb.	64 ft. per sec.	$\frac{10 \times 64 \times 64}{64}$ = 640 ft. lb.	800 + 640 = 1,440
3 sec.	0 ft.	0 ft. lb.	96 ft. per sec.	$\frac{10 \times 96 \times 96}{64}$ = 1,440 ft. lb.	0 + 1,440 = 1,440

u = 60 m.p.h. = 88 ft. per sec. v = 0. S = 60 yards = 180 feet.

Eqn. 4: $v^2 = u^2 + 2aS$

$$0 = 88^2 + 2 \times a \times 180$$

$$\therefore -88^2 = 2 \times a \times 180$$

$$\therefore a = \frac{-(88 \times 88)}{2 \times 180}$$

$$= -21{\cdot}5 \text{ ft. per sec. per sec.}$$

Acceleration $= -21{\cdot}5$ ft. per sec. per sec.

Retardation $= 21{\cdot}5$ ft. per sec. per sec.

Example (e): In an acceleration test, a sports car covered a quarter of a mile from a standing start in 20 seconds. Find the average acceleration.

$$S = \tfrac{1}{4} \text{ mile} = \frac{5{,}280}{4} \text{ ft.} = 1{,}320 \text{ ft.}$$

u = 0. t = 20 seconds.

Eqn. 3: $S = ut + \frac{1}{2}at^2$

$$1{,}320 = (0 \times 20) + (\tfrac{1}{2}a \times 20^2)$$

$$1{,}320 = 0 + (\tfrac{1}{2} \times 20 \times 20 \times a)$$

$$1{,}320 = 200a$$

$$\therefore a = \frac{1{,}320}{200} = 6{\cdot}6$$

The acceleration is 6·6 ft. per sec. per sec.

THE ACCELERATION DUE TO GRAVITY

A body released above the surface of the Earth is subjected to an acceleration, due to gravity, of 32 ft. per sec. per sec, or 981 cm. per sec. per sec. For example:

Time after Release in secs.	*Speed toward Earth ft. per sec.*	*cm. per sec.*
0	0	0
1	32	981
2	64	1,962
3	96	2,943
4	128	3,924
5	160	4,905

This acceleration is referred to as "g". g=32 ft. per sec. per sec. or 981 cm. per sec. per sec.

Example 1: A stone is dropped from a height. What will be its speed after 10 seconds?

u = 0. t = 10 sec. a = g = 32 ft. per sec. per sec. v = u + at.

v = 0 + (32 × 10) = 0 + 320 = 320 ft. per sec.

Example 2: A stone is shot vertically upward from a catapult with a speed of 90 ft. per sec. What will be its speed 2 seconds later?

u = 90 ft. per sec. (upward)

a = g = 32 ft. per sec. per sec. downward
= − 32 ft. per sec. per sec. upward.

t = 2 seconds.

v = u + at = 90 + (− 32 × 2) = 90 − 64 = 26.

Speed = 26 ft. per sec. upward.

Example 3: What will be the speed of the same stone after 3 seconds?

v = u + at = 90 + (− 32 × 3)
= 90 − 96 = − 6 ft. per sec.

The speed is − 6 ft. per sec. upward, i.e. + 6 ft. per sec. downward.

The stone has already reached its highest point and is on the way down with a speed of 6 ft. per sec.

Example 4: A cricket ball is thrown vertically upward with a speed of 96 ft. per sec. How long does it take to reach the highest point?

$$v = u + at.$$

Reckon upward as positive.

At turning point ball ceases to rise.

∴ v = 0. u = 96 ft. per sec. a = 32 ft. per sec. per sec.

$$0 = 96 + (-32 \times t)$$

$$\therefore 0 = 96 - 32t$$

$$\therefore 32t = 96 \qquad \therefore t = 3.$$

The ball is 3 seconds on its upwards journey.

As a matter of interest, the return journey takes exactly the same time, the speeds on the upward and downward journeys being identical (although opposite in direction) at every point; e.g. 0 ft. per sec. at the extreme altitude and 96 ft. per sec. at the ground. The total time in the air is therefore 6 seconds.

Example 5: A stone is dropped down a deep well and is seen to splash into the water 5 seconds later. How far below the top of the well is the water level?

u = 0 ft. per sec.

a = g = 32 ft. per sec. per sec.

t = 5 sec.

$$S = ut + \tfrac{1}{2}at^2$$

$$= (0 \times 5) + (\tfrac{1}{2} \times 32 \times 5^2)$$

$$= 0 + (16 \times 25) = 400.$$

The distance is 400 feet.

Example 6: A stone is dropped from the edge of a cliff 1,600 feet high. How long does it take to reach the water?

u = 0 ft. per sec.

S = 1,600 ft.

a = g = 32 ft. per sec. per sec.

$$S = ut + \tfrac{1}{2}at^2$$

$$\therefore 1{,}600 = (0 \times t) + (\tfrac{1}{2} \times 32 \times t^2)$$

$$\therefore 1{,}600 = 0 + 16t^2$$

$$\therefore 100 = t^2$$

$$\therefore t = 10.$$

Time is 10 seconds.

Drawing the path of a stone thrown from a cliff

Take the cliff as 400 feet high, and the horizontal velocity of the stone to be 60 ft. per sec.

Vertical Movement

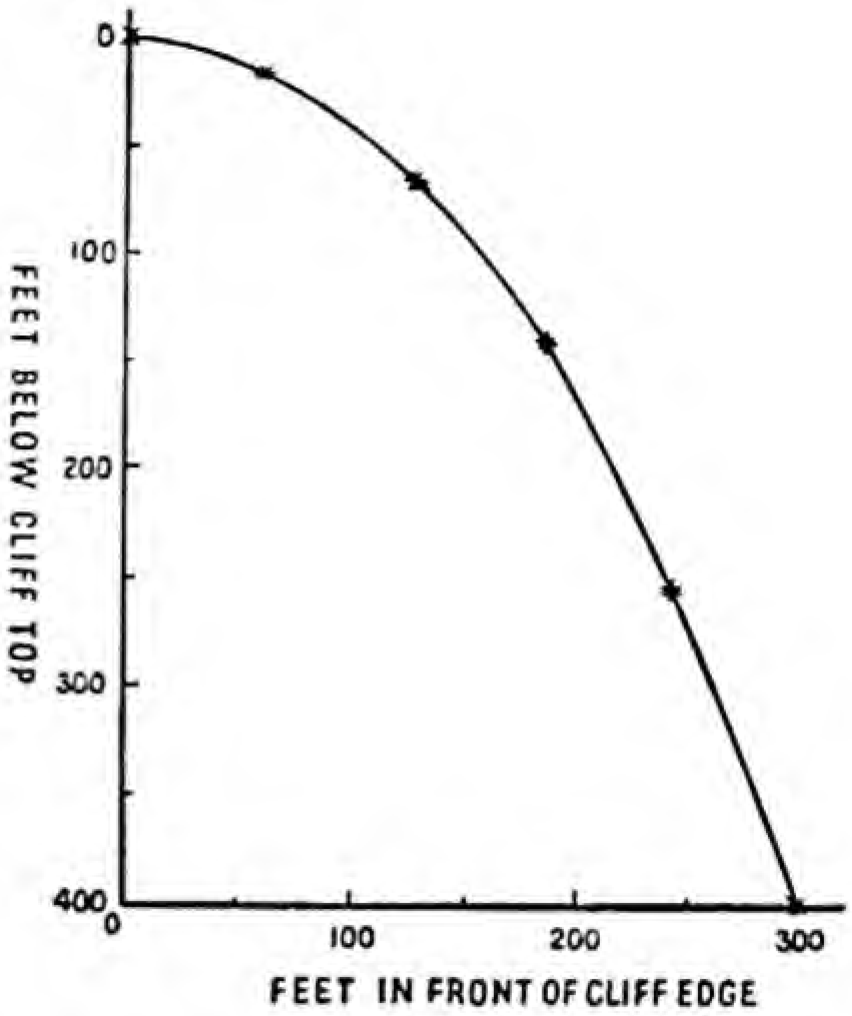
$$S = ut + \tfrac{1}{2}at^2 = (0 \times t) + (\tfrac{1}{2} \times 32 \times t^2) = 16t^2.$$

Horizontal Movement

$$S = u \times t = 60 \times t = 60t.$$

Time (sec.)	*Vertical drop (feet)*
0	0
1	16
2	64
3	144
4	256
5	400
6	576
7	784
8	1024

Time (sec.)	*Horizontal flight (feet)*
0	0
1	60
2	120
3	180
4	240
5	300
6	360
7	420
8	480



Drawing the path of an object shot into the air at an angle, e.g. a cricket ball

Note: The object keeps its original velocity unchanged, and receives, in addition, an extra velocity, vertically downward, due to gravity.

Example: A cricket ball hit with a velocity of 80 ft. per sec. at an angle of 45° with the ground.

The position of the ball is shown after every $\frac{1}{4}$ second (page 224).

Vertical Drop

$$S = ut + \tfrac{1}{2}at^2 = (0 \times t) + (\tfrac{1}{2} \times 32t^2) = 16t^2.$$

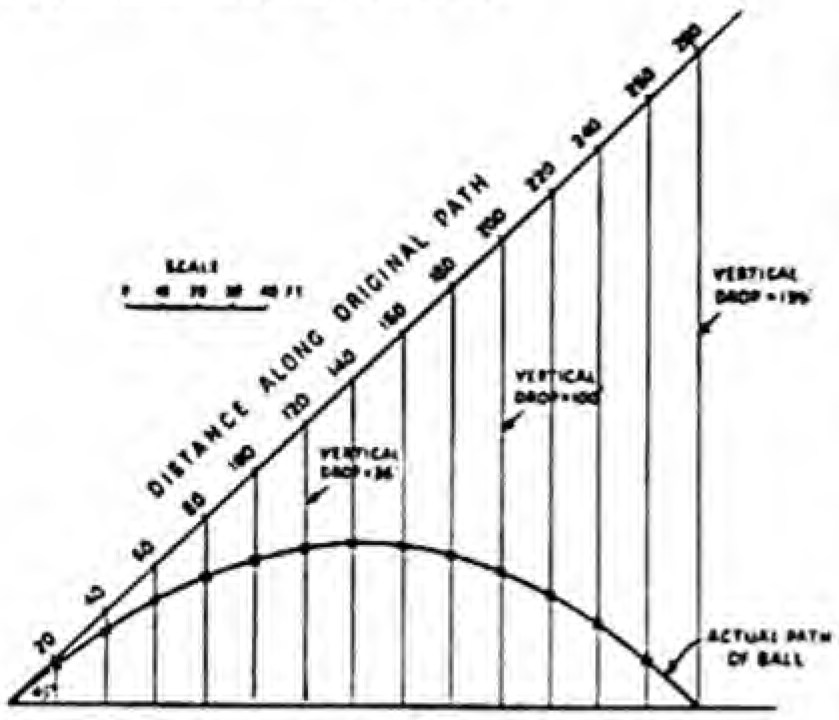
Movement along original path

$$S = u \times t = 80t.$$

Time (sec.)	*Vertical drop (feet)*
0	0
$\frac{1}{4}$	1
$\frac{1}{2}$	4
$\frac{3}{4}$	9
1	16
$1\frac{1}{4}$	25
$1\frac{1}{2}$	36
$1\frac{3}{4}$	49
2	64
$2\frac{1}{4}$	81
$2\frac{1}{2}$	100
$2\frac{3}{4}$	121
3	144
$3\frac{1}{4}$	169
$3\frac{1}{2}$	196
$3\frac{3}{4}$	225
4	256
$4\frac{1}{4}$	289
$4\frac{1}{2}$	324
$4\frac{3}{4}$	361
5	400

Time (sec.)	*Distance along original path (feet)*
0	0
$\frac{1}{4}$	20
$\frac{1}{2}$	40
$\frac{3}{4}$	60
1	80
$1\frac{1}{4}$	100
$1\frac{1}{2}$	120
$1\frac{3}{4}$	140
2	160
$2\frac{1}{4}$	180
$2\frac{1}{2}$	200
$2\frac{3}{4}$	220
3	240
$3\frac{1}{4}$	260
$3\frac{1}{2}$	280
$3\frac{3}{4}$	300
4	320
$4\frac{1}{4}$	340
$4\frac{1}{2}$	360
$4\frac{3}{4}$	380
5	400

The drawing shows that the ball returns to its original horizontal level 199 feet from where it was thrown. It is in the air for approximately $3\frac{1}{2}$ seconds.



THE EFFECT OF AIR RESISTANCE ON THE RATE OF FALLING UNDER GRAVITY. It is quite true to say that the force of gravity treats all substances alike, and that it gives both to lead shot and to feathers the same downward acceleration of 32 ft. per sec. per sec. Yet experience tells us that lead shot rush to the ground with considerable speed when released, while feathers drift slowly downward. The explanation is the resistance of the air, which has a much greater effect on the large surface of the feather than on the tiny surface of a lead shot of equal weight. Lead shot and feathers do, however, fall at exactly the same rate in the absence of air, i.e. in a vacuum.

According to our velocity equations, the speed of a body dropping from a height increases regularly, reaching a very high value indeed where the height is considerable.

For example:

Time of falling (sec.)	Total distance fallen (feet)	Speed (ft. per sec.)	Speed (m.p.h.)
1	16	32	22
2	64	64	44
3	144	96	65
4	256	128	87
5	400	160	109
6	576	192	131
7	784	224	153
8	1,024	256	175
9	1,296	288	196
10	1,600	320	218
11	1,936	352	240
12	2,304	384	262
13	2,704	416	284
14	3,136	448	305
15	3,600	480	327
20	6,400	640	436
30	14,400	960	655
40	25,600	1,280	873
50	40,000	1,600	1,094

According to these calculations, a man falling from an aeroplane at 40,000 feet would reach the ground in 50 seconds, and strike it with the speed of over 1,000 m.p.h. In practice, due to air resistance, the time is very much longer, and the speed with which he falls is limited to approximately 120 miles per hour. This limiting speed depends upon the weight and the surface area of the body. The larger the surface area, the greater the air resistance and the slower the fall. The surface area of an airman can be made very great indeed by giving him a parachute. With this, his limiting speed may be as low as 12 m.p.h., compared with the speed through air of 120 m.p.h. without a parachute, or of 1,000 m.p.h. or more in a vacuum.

MOMENTUM. The momentum of a body is a measure of its effect in a collision with other bodies. It is the *product of its mass and velocity*.

If it is assumed that no energy is used up in a collision, e.g. in producing heat or causing damage, then *total momentum of bodies before a collision = total momentum of bodies after collision.*

Example 1: A railway truck weighing 4 tons and moving at 5 m.p.h. collides with a stationary truck weighing 5 tons, and they move on together. Find the speed after collision.

Total momentum before collision

$= 4 \text{ tons} \times 5 \text{ m.p.h.} + 5 \text{ tons} \times 0 \text{ m.p.h.}$

Total momentum after collision

$= (4 \text{ tons} + 5 \text{ tons}) \times V \text{ m.p.h.}$

$\therefore 20 + 0 = 9 \times V$

$\therefore 20 = 9V$

$V = 2\frac{2}{9}$ m.p.h.

Example 2: A bullet weighing 1 ounce is fired with a velocity of 10,000 ft. per second from a rifle weighing 10 lb. Calculate the speed of recoil of the rifle.

First momentum = 0, since no movement.

$\therefore$ Total momentum after firing = 0.

$\therefore \frac{1}{16}$ lb. $\times$ 10,000 ft. per sec. + 10 lb. $\times$ v ft. per sec. = 0.

$$\therefore 10v = -\frac{10{,}000}{16}$$

$$\therefore v = -\frac{1{,}000}{16}$$

$$= -62{\cdot}5$$

The speed of recoil is 62·5 ft. per sec. in the opposite direction to that of the bullet.

THE CONNECTION BETWEEN FORCE AND ACCELERATION. Force is proportional to the acceleration produced. Force is proportional to the mass accelerated—i.e. P is proportional to m and a.

Equation: $P \times g = m \times a$.

Using feet, lb. and seconds as units, $32P = m \times a$.

Using cm., gm. and seconds as units, $981P = m \times a$.

Example 1: What force will be required to give a mass of 2,000 gm. an acceleration of 20 cm. per sec. per sec.?

$P \times g = m \times a$

$P \times 981 = 2{,}000 \times 20$

$$\therefore P = \frac{40{,}000}{981} = 40{\cdot}8 \text{ gm. approx.}$$

Example 2: A girl weighing 6 stones 12 lb. is in a lift which starts upward with an acceleration of 5 ft. per sec. per sec. How much does she seem to weigh while the lift accelerates?

6 st. 12 lb. = 96 lb.

$32P = m \times a.$

$32 \times P = 96 \times 5$

$$\therefore P = \frac{96 \times 5}{32} = 15$$

The lift has to push upward on her feet with a force of 15 lb. to give her the required acceleration. There is also a force of 96 lb. due to her weight. She seems to weigh 96 lb. + 15 lb. = 111 lb. = 7 st. 13 lb. while the lift accelerates.

Example 3: A balloon of total weight 6,500 lb. is drifting at a constant altitude. What will be the upward acceleration when 100 lb. of ballast are dropped? Upward force on balloon is now 100 lb. wt.

Weight of balloon = 6,500 lb. − 100 lb. = 6,400 lb.

$P \times g = m \times a$

$\therefore 100 \times 32 = 6{,}400 \times a$

$\therefore 3{,}200 = 6{,}400\,a$

$$\therefore a = \frac{3{,}200}{6{,}400} = \frac{1}{2}$$

The acceleration is $\frac{1}{2}$ ft. per sec. per sec.

Example 4: A car weighing 1 ton is moving with a steady speed of 30 m.p.h. when the brakes are applied, giving a constant retarding force of 1,540 lb. weight. Calculate the retardation produced, and the distance the car moves before coming to rest.

To find retardation:

$P \times g = m \times a$

$\therefore 1{,}540 \times 32 = 2{,}240 \times a$

$$\therefore a = \frac{32 \times 1{,}540}{2{,}240} = \frac{1{,}540}{70}$$

$$= 22.$$

The retardation is 22 ft. per sec. per sec.

To find distance travelled:

$v^2 = u^2 + 2as$ (see page 222).

$v = 0$ (car at rest).

$u = 30$ m.p.h. = 44 ft. per sec.

$a = -22$ (retardation of 22 ft. per sec. per sec.—see above).

S = distance in feet.

$v^2 = u^2 + 2as$

$0 = 44^2 - 2 \times 22 \times S$

$\therefore 2 \times 22 \times S = 44^2$

$\therefore 44\,S = 44^2$

$$\therefore S = \frac{44^2}{44} = 44.$$

The car will travel 44 feet before stopping.

NEWTON'S LAWS OF MOTION (1686).

The First Law of Motion. Every body continues in its state of rest or of uniform motion in a straight line unless compelled by the application of a force to change from that state.

The Second Law of Motion. When a body is acted upon by a force, the increase in the acceleration of the body is proportional to the force applied, and takes place in the direction of this force.

The Third Law of Motion. To every Action there is an equal and opposite Reaction.

INDEX

There are two indexes to this Encyclopaedia, a main one of the conventional sort and a subject index which is designed to help the reader find a reference when he is not sure of the scientific name for it. The entries in this subject index also show the relatedness of the various sciences.

The easiest way to use the subject index is to decide which of the headings is most likely to cover the subject you want and then run through all the entries under that heading.

MAIN INDEX

SUBJECT INDEX

THE WORLD

FOOD

CHEMISTRY

HUMAN BEINGS

ENGINEERING

WATER

RADIATIONS

LIGHT

HEARING

WAVEFORMS

PHYSICS

AIRCRAFT

SHIPS

SCIENTIFIC LAWS AND FORMULAE

ELECTRICITY AND MAGNETISM

HOUSEHOLD EQUIPMENT

INVENTIONS

NAVIGATION

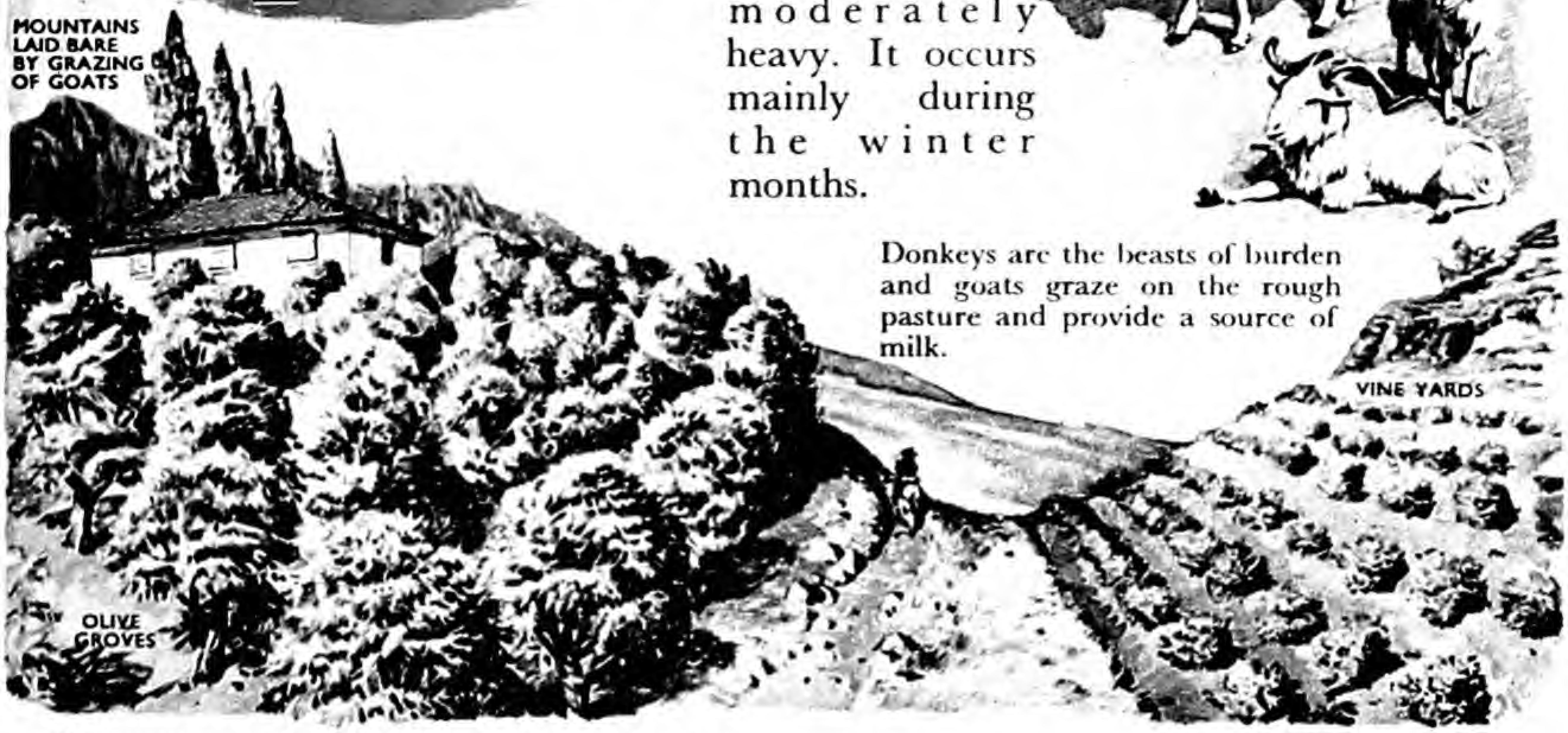
BIOLOGY

Mediterranean Type

These regions experience very hot summers and warm winters.

Rainfall is moderately heavy. It occurs mainly during the winter months.

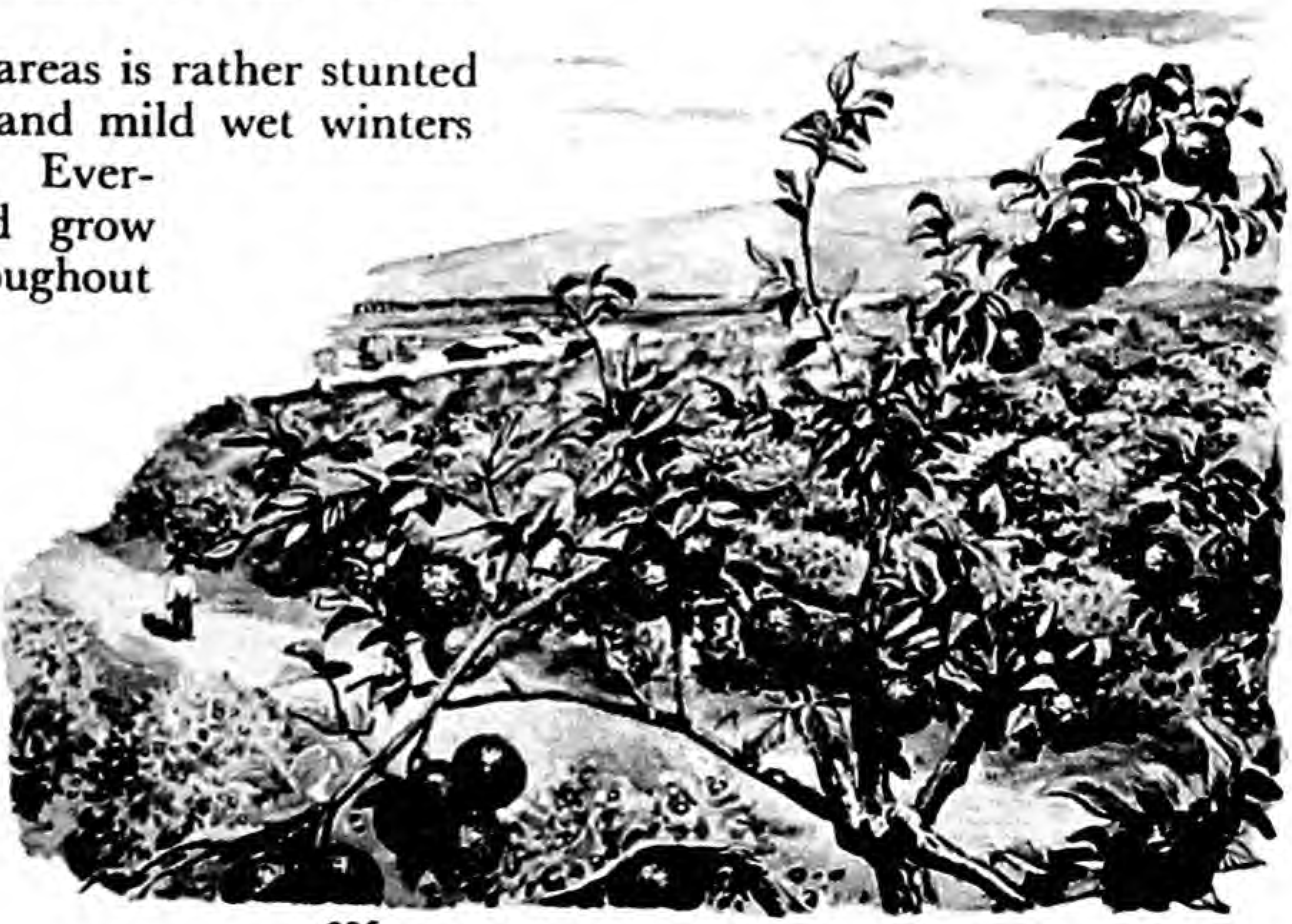
Donkeys are the beasts of burden and goats graze on the rough pasture and provide a source of milk.



Summer rather than winter is the season unfavourable to growth.

The vegetation of these areas is rather stunted as the long dry summers and mild wet winters permit only slow growth. Evergreens are abundant and grow slowly and uniformly throughout the year, (*see page* 232).

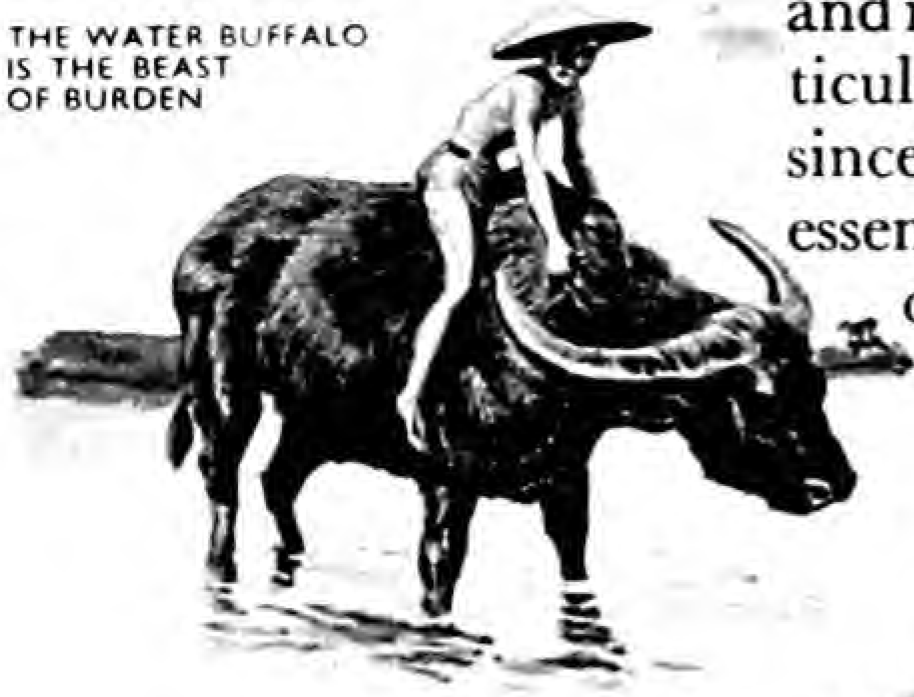
The type of climate is particularly suited to the cultivation of olives, citrus fruits and vines; the cultivation of these crops represents the principal industry.

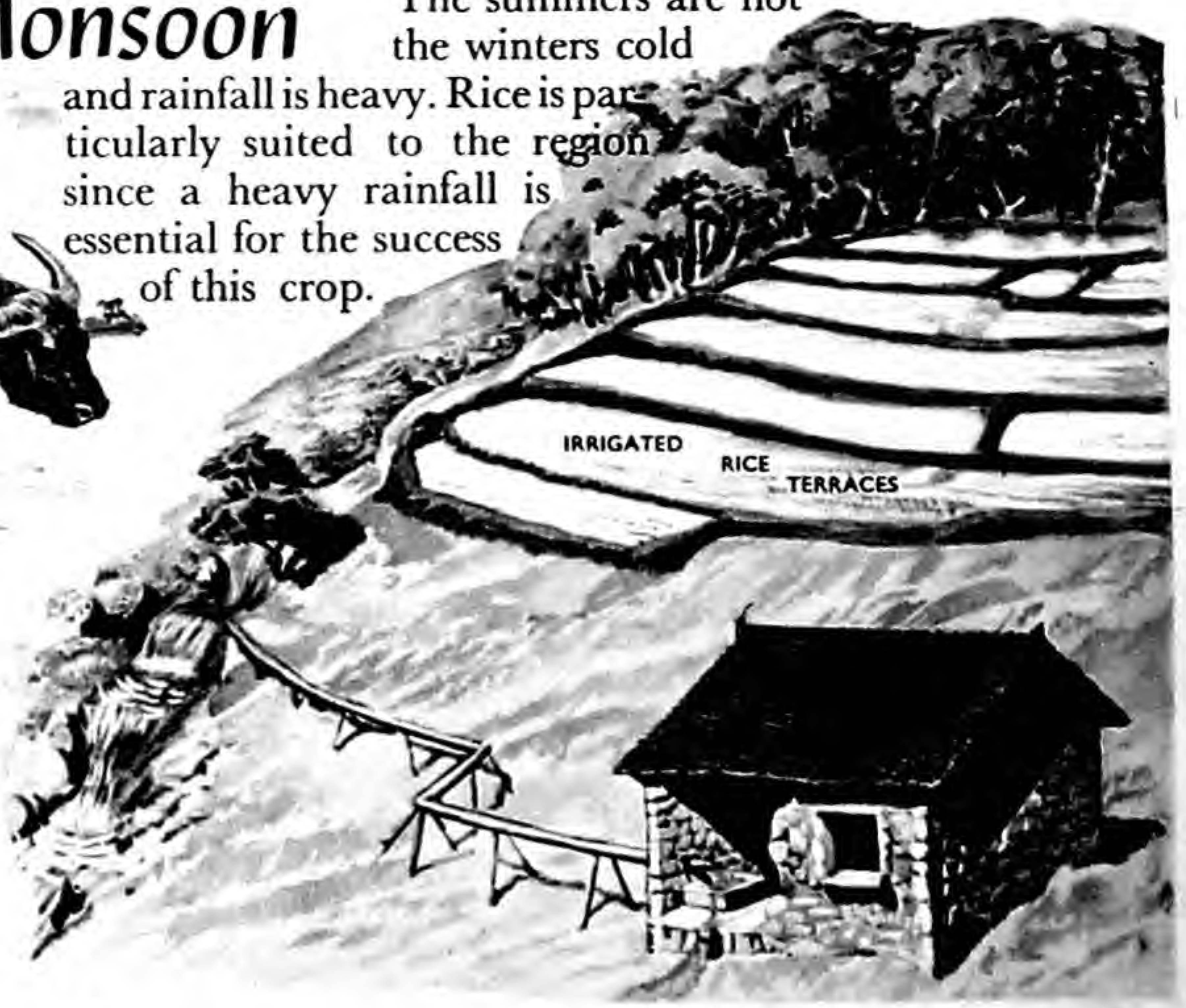


Olives and oranges are cultivated on a large scale in areas with this climate. Figs, lemons, peaches, nuts are also grown.

Temperate Monsoon

The summers are hot the winters cold and rainfall is heavy. Rice is particularly suited to the region since a heavy rainfall is essential for the success of this crop.



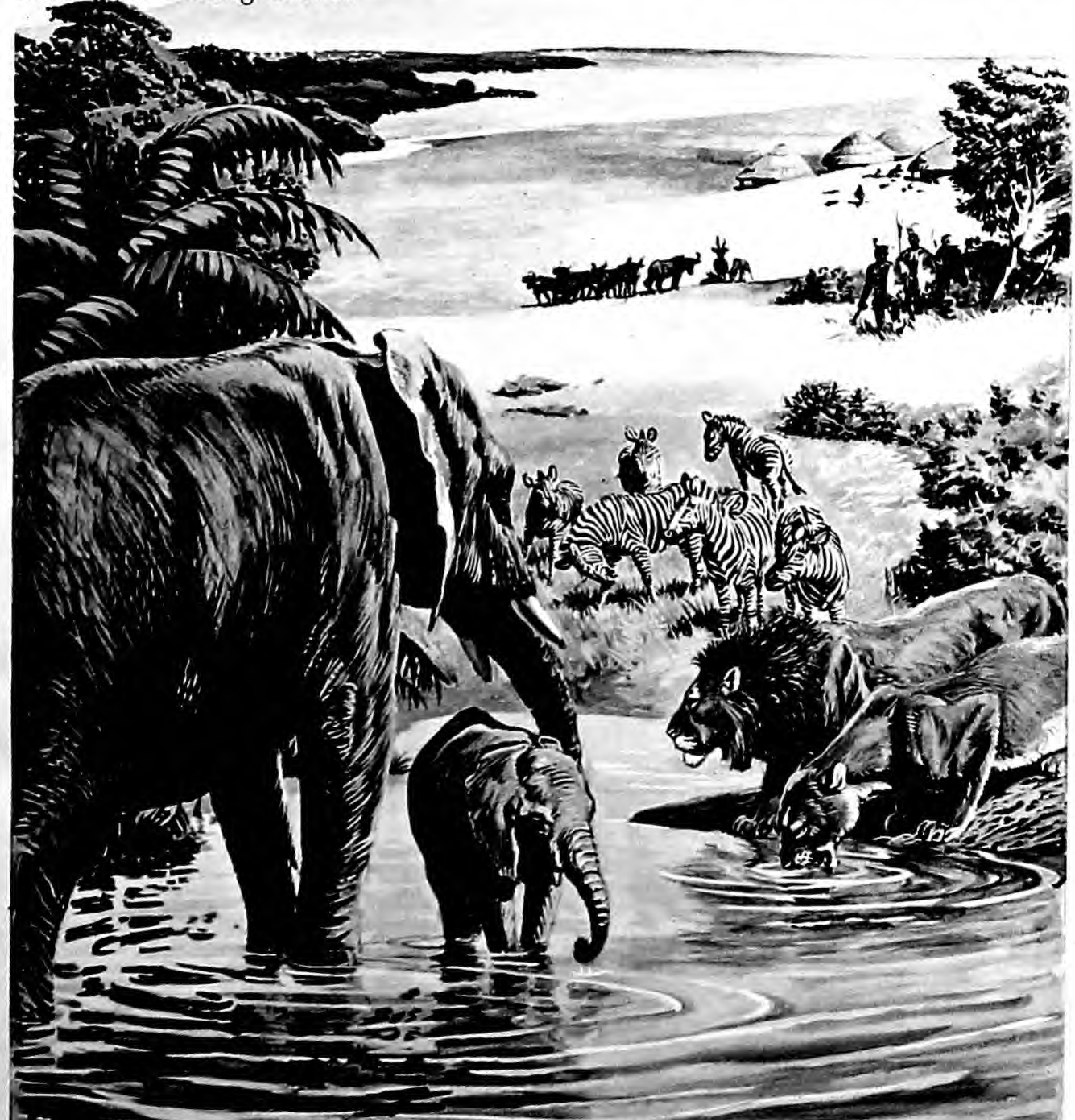


Steppe Type - Australian Plains

Steppe lands are vast grass lands deep within the continents. They have hot summers and very cold winters with only a little rain throughout the year. The vegetation is mainly of coarse grasses or low bushes. Sheep can exist on these and in the Australian plains sheep-running has been developed on a large scale.

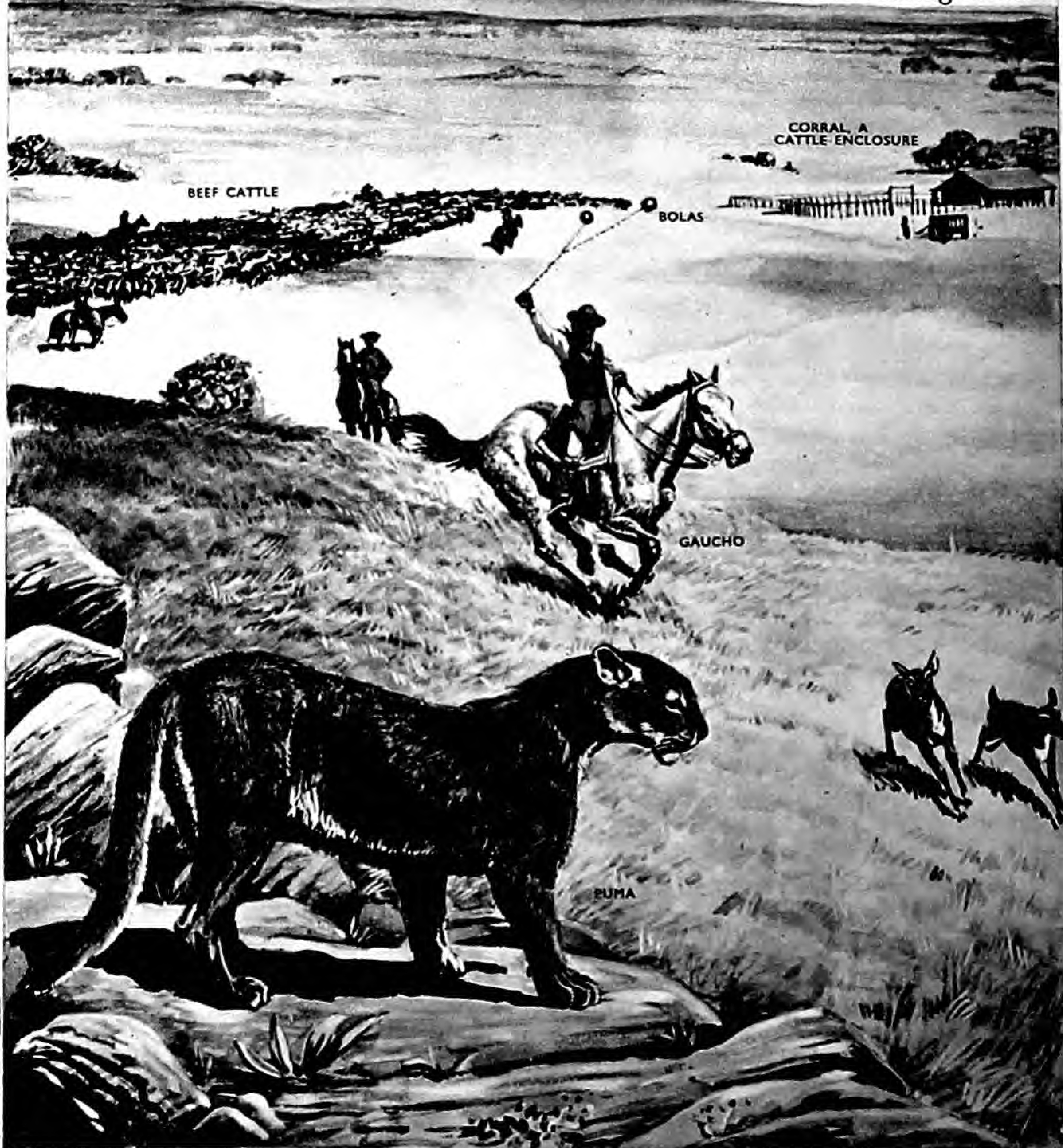
Steppe Type - South African Veldt

The steppes of southern Africa, the veldt, are probably the most under developed of all the steppe-lands. Herds of wild animals still roam about and, at certain times, elephants leave the forests and descend to the water holes. The native inhabitants of the veldt live by keeping small herds of oxen which give them milk and meat as well as skins for making clothes.



Steppe Type - South American Pampas

The steppes of the southern hemisphere are generally warmer than those of the northern, for the continents in the south are narrow and nowhere is the influence of the sea entirely absent. The Argentine steppe, which is known as the 'pampas', supports many thousand head of cattle and is one of the world's foremost cattle rearing areas.



HOW PLANTS SURVIVE FROM ONE GROWING SEASON TO THE NEXT

ANNUALS survive through their seeds.


Poppy.


Wheat.


Maize.


The roots of a poppy.


A poppy seed capsule.


A close-up of a seed.


A seed germinating.

Most plants grow best at one season and rest from growing during the part of the year that is more difficult for them. The growing season is not always summer; even in a temperate climate like that of England some plants grow best in spring or autumn, while in other climates the very dry summer is the difficult season and the plants tend to grow in autumn or winter. In deserts the bad season can last for several years if rain only falls once every five years or so.

Some plants live on from season to season, these are called perennials; others called annuals, which must die at the end of the season leave only seeds to carry on their race.

Herbaceous perennials last through their bad season by withdrawing underground, where they have stored their reserves. They have underground organs which have buds on them and these organs store food as sugar or starch for their first growth in the next season. New growth starts from the little buds. Deciduous trees live through the bad season by means of "resting buds" specially protected by little scales.

Evergreen trees have leaves that lose water slowly to contend with dry hot summers. As the water evaporates slowly so the sugar lift acts slowly (*see page* 37), and the lesser flow of water through the plant reduces the amount of minerals that can be brought up from the soil. So evergreens grow slowly, but they make up for it by continuing to grow right through

PERENNIALS live on from season to season.


Bluebell.


Sugar Cane.


Michaelmas daisy.


Bluebell bulb.


A flower.


Dropping new bulb.

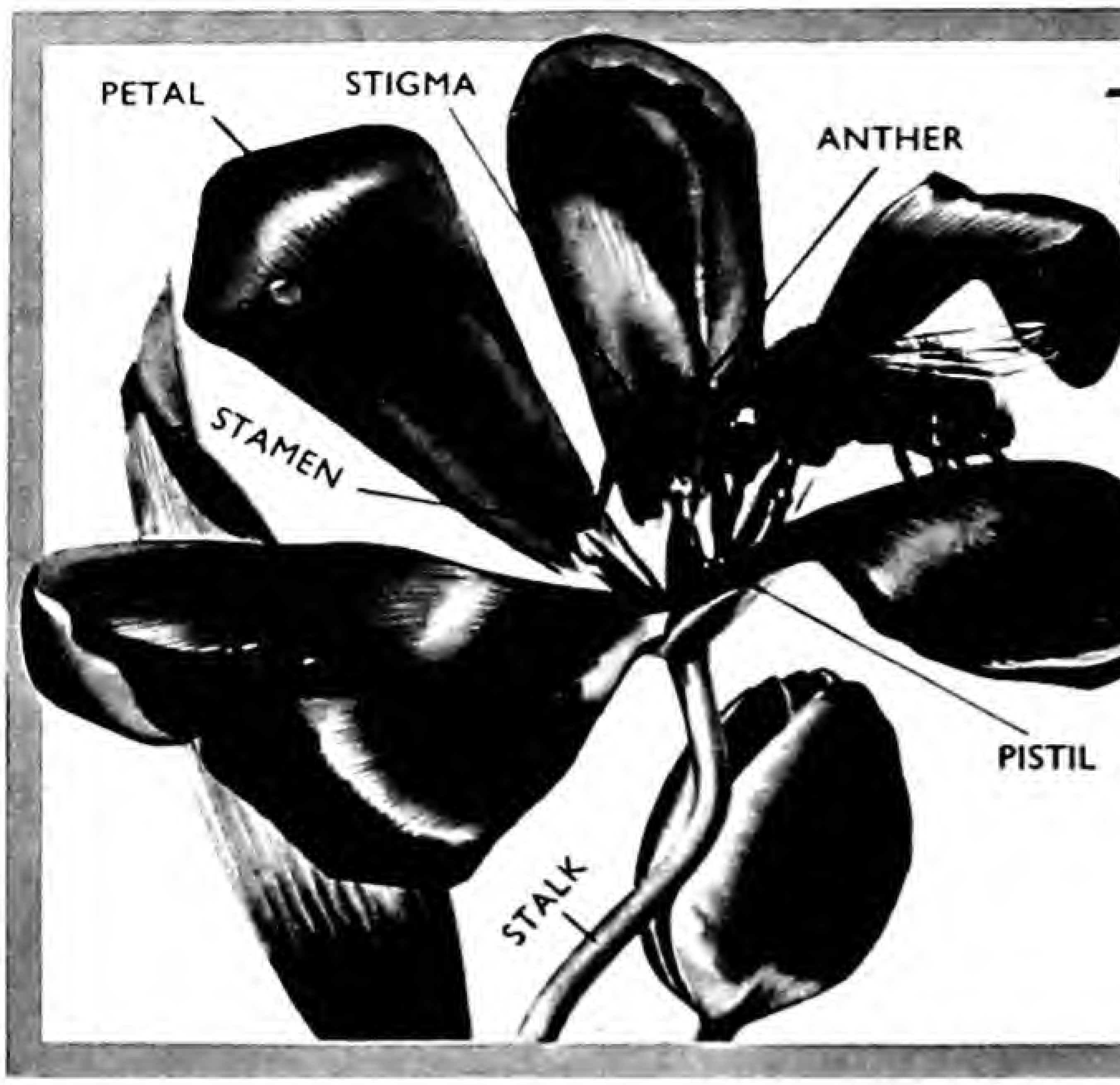

Bluebell seed sprouting.


A michaelmas daisy in flower.


The flowers and fruit.


The fruits blowing away.


Roots spreading to make new plants.



The Parts of a Flower and their Function

The flower has an important part to play in the life of a plant for here the seeds are produced that enable the race to be carried on. The young seeds (ovules) grow at the bottom in a tube called the pistil at the tip of which is the stigma. Surrounding the pistil are slender stalks, the stamens, each divided into two parts, the top half being called the anther.

In order to grow into seeds the ovules must be fertilised by pollen produced in the anther. Pollen is transferred to the pistil in many ways. In some plants, insects such as bees, in others the wind, may carry it from flower to flower. Or the anther itself may brush against the stigma.

the winter too. Their chief hazard in colder regions is that they may wilt in winter when they cannot get water from soil that is frozen.

The house leek, a British water storing plant, grows on house roofs where there is no soil.

The desert cactus is a slow growing plant which stores water in order to survive the dry season.

The seed is essential for the increase and dispersal of both annuals and perennials. In the case of annuals, it is also necessary for survival to the next season.

In ploughland weed plants are buried by the ploughshare turning over the topsoil. Annuals like poppies, because they survive as seed, can endure these disasters.

Perennials such as the dock do not like ploughland, because they have to start again each time the ground is turned over.

Seeds can, if necessary, remain dormant in the soil for very long periods. This is seen when poppies appear again after many years when the ground is cultivated because new ploughing has brought the old seeds close enough to the surface to sprout.

The seed grows in the flower in a tube called the pistil.

THE CLASSIFICATION OF PLANTS

GREEN SEAWEED BROWN SEAWEED LIVERWORT MOSS FERN FUNGI LICHEN

How Plants Live in Difficult Conditions

Some plants need large quantities of water in order to live, others exist on very little. Desert plants which have to endure droughts may have seeds of long dormancy which will germinate after many years, or they may have underground tubers and bulbs which shoot only when they receive a little rain. Such plants when growing are often helped by cold nights which condense the moisture of the air in the spaces of the top soil. Other plants, like cactus and euphorbia, being slow growing plants endure the dry season sustained by water stored in their fleshy tissues.

The Arrowhead conveys air through leaf-stalks to its roots in the mud.

The Jusseia repens lives in water. In order for the plant to get enough air, roots protrude above the surface like the breathing device on a submarine.

The liana of tropical forests twists itself around trees, climbing to their tops to reach the light.

The honeysuckle, too, is a climbing plant, spreading out from the parent stem to catch as much light as it can.

Plants which grow in sea water are also short of water because it is more difficult for the sugar lift (*see page* 37) to pull up fresh water from salty water since salt also has an opposing " lift " effect.

All growing tissue needs to respire (that is burn up tissue with oxygen) in order to grow. In well drained soils roots get their oxygen direct from air spaces in the soil. Plants which live in water-logged airless soil feed air to their roots from their wide spreading leaves through tubes. Plants like watercress growing in flowing water which contains enough dissolved air, are able to get their oxygen from the water.

Plants are also in competition with each other. Taller plants catch all the light making it more difficult for

CLUB MOSS HORSETAIL CYCAD CONIFER MONOCOTYLEDON DICOTYLEDON

Monocotyledons (top row) are plants with only one seed leaf while dicotyledons (bottom two rows) have two.

Deciduous trees are those that lose and renew their leaves every year. The horsechestnut (*left*) and magnolia yulam (*right*) are two examples.

Dormant bud of horse-chestnut | Its seasonal flowers and leaf. | Fruit with seed (conker).

others to grow in their shade. Only " shade tolerant " species grow under trees with thick foliage ; some such as primrose, succeed here because they are able to grow in early spring before the leaves of the trees are spread.

Plants are also in competition for water and minerals from the soil. Some plants, like dandelion, grow deep tap roots to meet this competition, while others growing near them have spreading roots close to the surface which are better able to make use of slight showers of rain during a drought.

Evergreen trees are those that keep their leaves all the year round. The holly (*left*) is an example in temperate lands, while the banana tree (*right*) is a tropical example. Most tropical trees are evergreen.

The HILLS of BRITAIN

Splitting slates from the Ordovician rocks of N. Wales.

Mechanical coal cutting. The coal seams marked on the cross section are within reach from the surface in Lancashire and Derby.

Sawing limestone from the Cotswolds and the Northamptonshire Uplands

Open cast iron ore mining where the iron bearing sands of the Jurassic rock come to the surface in Northamptonshire.

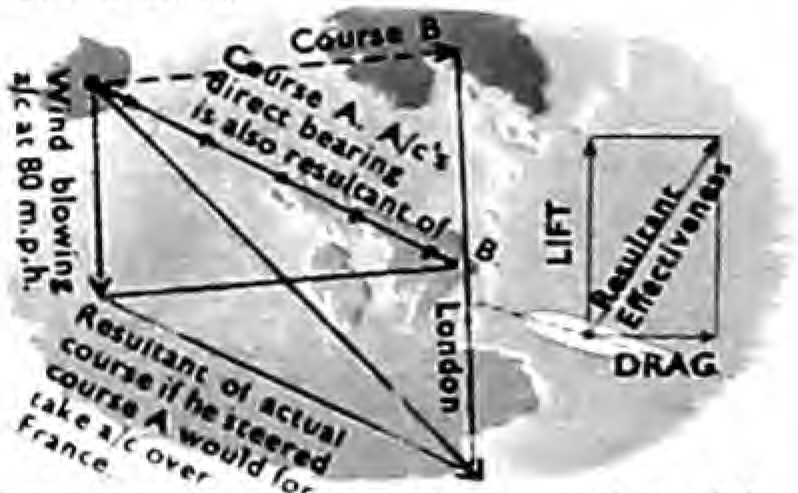
For remainder of Key see cross section below

The layers of rock are tilted or folded in different ways in different parts of the country. Here are some of the hills where one type of rock is the main one forming the range. How the layers were laid down is seen on page 21.

Splitting granite from the quarries of Devon and Cornwall.

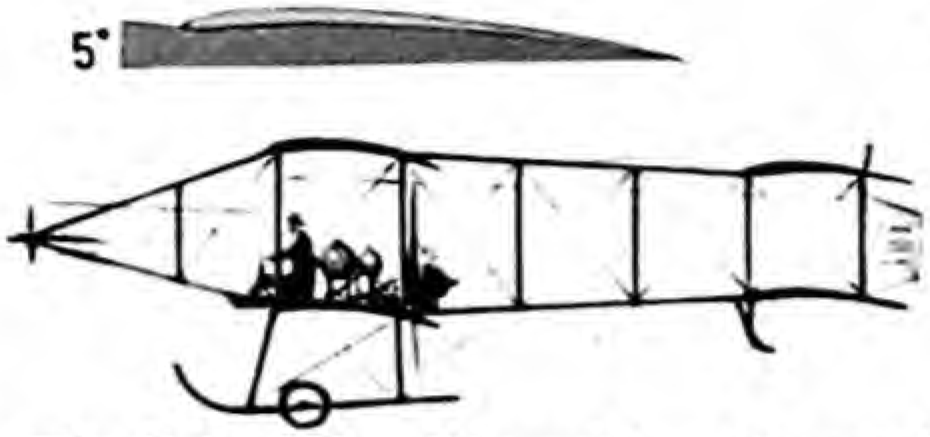
DESIGNING AEROFOILS

Pilot sets course B to allow for wind and parallelogram of both is London.



Just as the air pilot, setting his course, allows for the amount the wind will drift him off course, so an aircraft designer allows for the drag due to the speed of his aerofoil through the air. This drag is caused by the angle of attack of the aerofoil. The angle of attack decides the amount of lift at each speed. So the aircraft designer's parallelogram is of forces of drag and lift, the resultant is the flying effectiveness of his aerofoil.

5°



The Bristol Box Kite with a top speed of 40 m.p.h. had its wings at an angle of 5°.

4°

80 m.p.h. was the top speed of the Avro 504 K. Its wings were set at 4°.

3°

With a top speed of 115 m.p.h. the D.H. 9 A of the 1st World War had its wings at 3°.

3°

Also at 3° were the Bristol Bulldog's wings, although its top speed was 174 m.p.h.

2½°

The Battle of Britain Hurricane I was able to have its wings at 2½° with a top speed of 325 m.p.h.

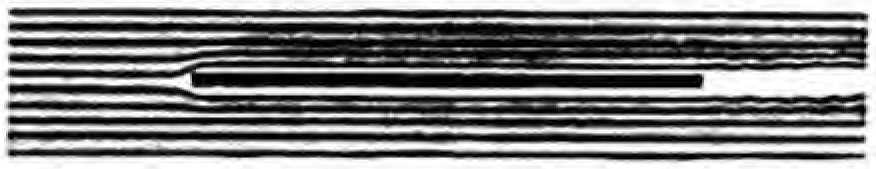
But it also had flaps to give it extra lift at take off and on landing.

1½°

The Hawker Tempest 5, one of the fastest planes of the 2nd World War with a speed of 435 m.p.h., had its wings at 1½°.

0°

Jet engined planes fly much faster than those with piston engines. In fact so fast that the wing no longer has to be at an angle to give enough lift for the plane to fly. This Fairey F.D. 2 Delta fighter, in order to be able to fly at the low speeds necessary for landing, actually comes in to land at an angle (the nose of the plane drops down so that the pilot can see where he is going) while a parachute further slows its speed.

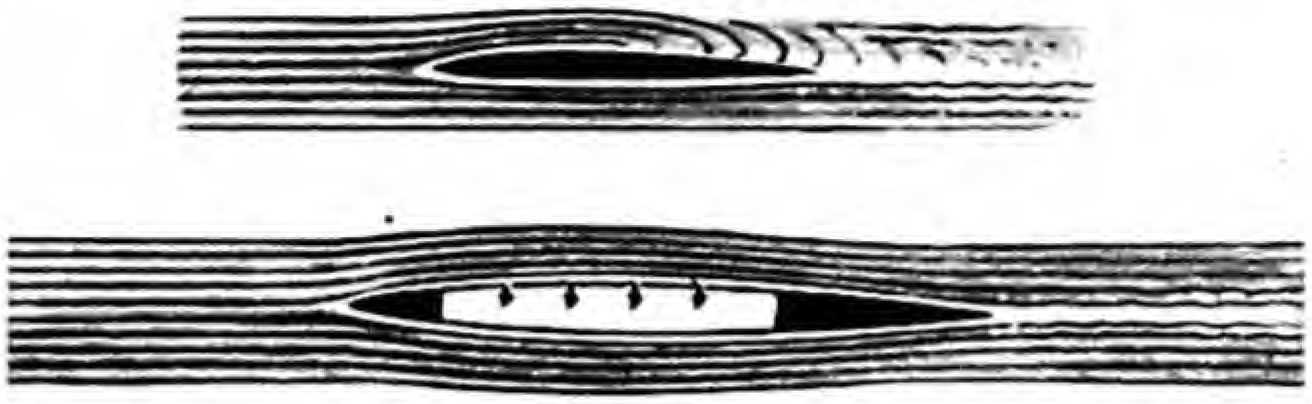


This flat plate lies level with the path of the air which flows smoothly around it without lifting it or pulling it down.

With the plate at an angle the air flowing under it pushes it upwards, but over it the bubbling of air creates drag and pulls it down.

In an aerofoil the path of the air over the top is longer than underneath. So the same amount of air above has to stretch, lessening the pressure above and the aerofoil will lift.

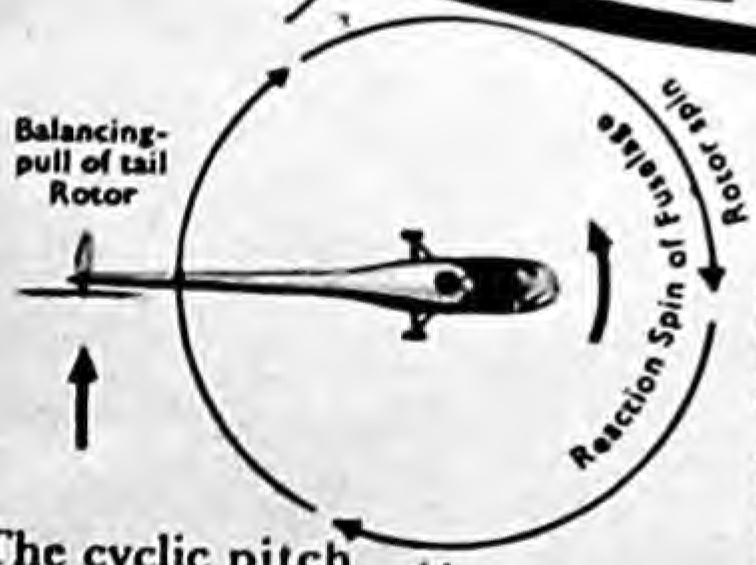
Slow moving aeroplanes which have a high wing angle are in danger of stalling (that is the top air breaks away) when they slow down to land. To overcome this the edge of the aerofoil has a slot in it which speeds up the air and makes it easier for it to cling to the surface of the wing.



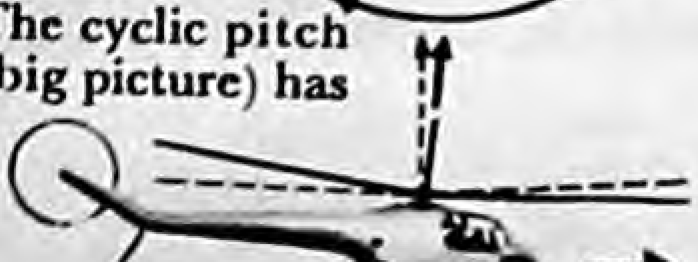
The fastest flying aeroplanes are also in danger of stalling when they come in to land at a slow speed, because the air moves slowly over the wing surface and tends to break away from it causing turbulence. This is prevented by sucking the air down through little holes in the wing. The suction is supplied by jet thrust bled from the main engine.

Flight Control of Helicopters

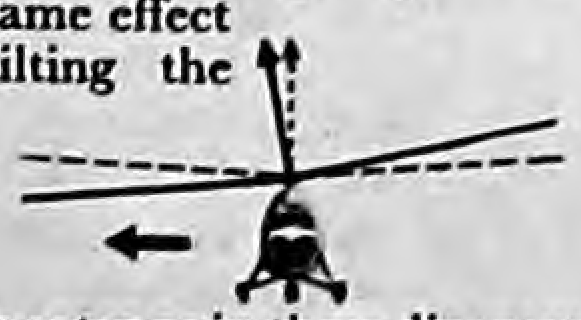
How the tail rotor balances the fuselage's reaction to the main rotor.



The cyclic pitch (big picture) has



the same effect as tilting the



whole rotor as in these diagrams.

Because of the way their rotor blades are arranged helicopters can take off and fly in any direction. The rotors of the Bristol Sycamore (*above*) show that to go forward the three blades are each tilted by a cam as they reach the back part of their circular motion, so that each takes a bigger 'bite' out of that part of the air. As each rotor blade goes on forward the cam turns it flat so it takes hardly any bite out of the air in front of the helicopter. So the helicopter flies forward. To go backwards the biggest bite would be taken out of the forward air. This is called cyclic pitch. Without the anti-torque rotor spinning side-ways at the tail, the reaction to the rotor spin would be that the helicopter itself would tend to spin in the direction of the rotor. Some helicopter designers eliminate the tail rotor by using two contra-rotating main rotors which cancel out each others torque.

This Bristol 173 has two large stepped rotors contra-rotating to cancel out each other's torque.

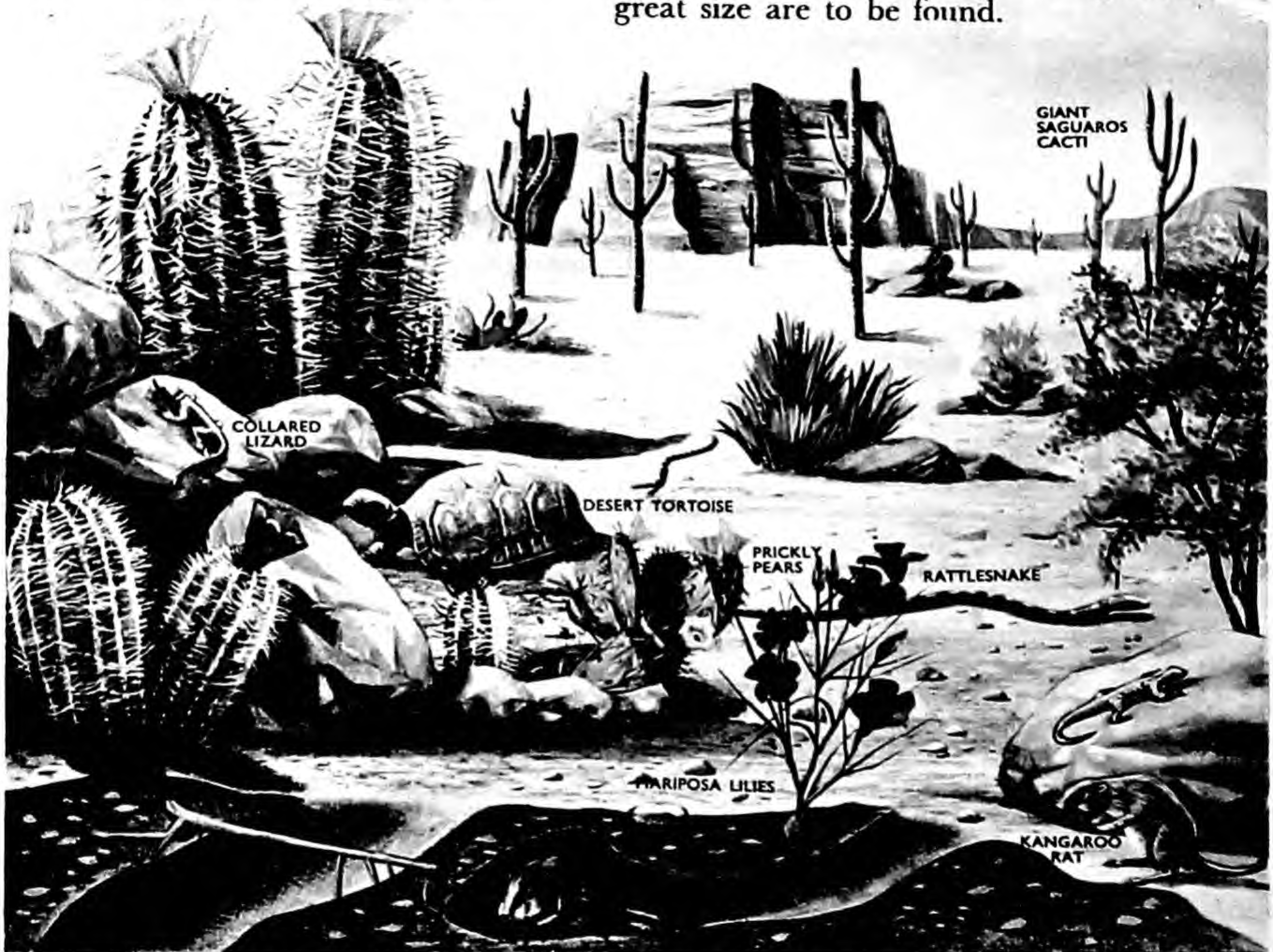
The Kaman H.T.K. has tilted inter-meshing rotors.

The Gyrodyne G.C.A.2. has one set of rotors on top of another.

HOT LANDS
New Mexico

The desert regions of the world.

This is one of the very hot regions of the world and because of the low rainfall, less than ten inches, it is only able to support plants that can withstand long periods of drought. Varieties of water storing cacti of great size are to be found.



Wide brimmed hats and loose clothing are worn.

Wide eaves and small windows keep out the sun.

The Sahara

The drier deserts of the world, such as parts of the Sahara, will not support even drought resisting plants. Because there are no plants to fix the soil, the land is either quite bare (of rock, hard sun-baked clay or strewn with boulders) or is buried under wind blown sand piled up into dunes.

Where subterranean water comes near the surface an oasis occurs and some form of agriculture is then possible. The oasis dwellers raise dates, fruits, maize and other crops. On the drier edges sheep and goats graze on a rough pasture.

Dwellers outside the oasis are purely nomadic. They rear small herds of sheep and camels and wander about those parts of the desert searching for small patches of scrub grass. For if erratic rainfall adds up to ten inches at any one place in a year, rough pasture can exist.

To the nomad the camel is indispensable for not only does it provide milk and clothing, but is able to travel for long distances without water.

Rats and scorpions are among the few creatures able to exist in the Sahara.

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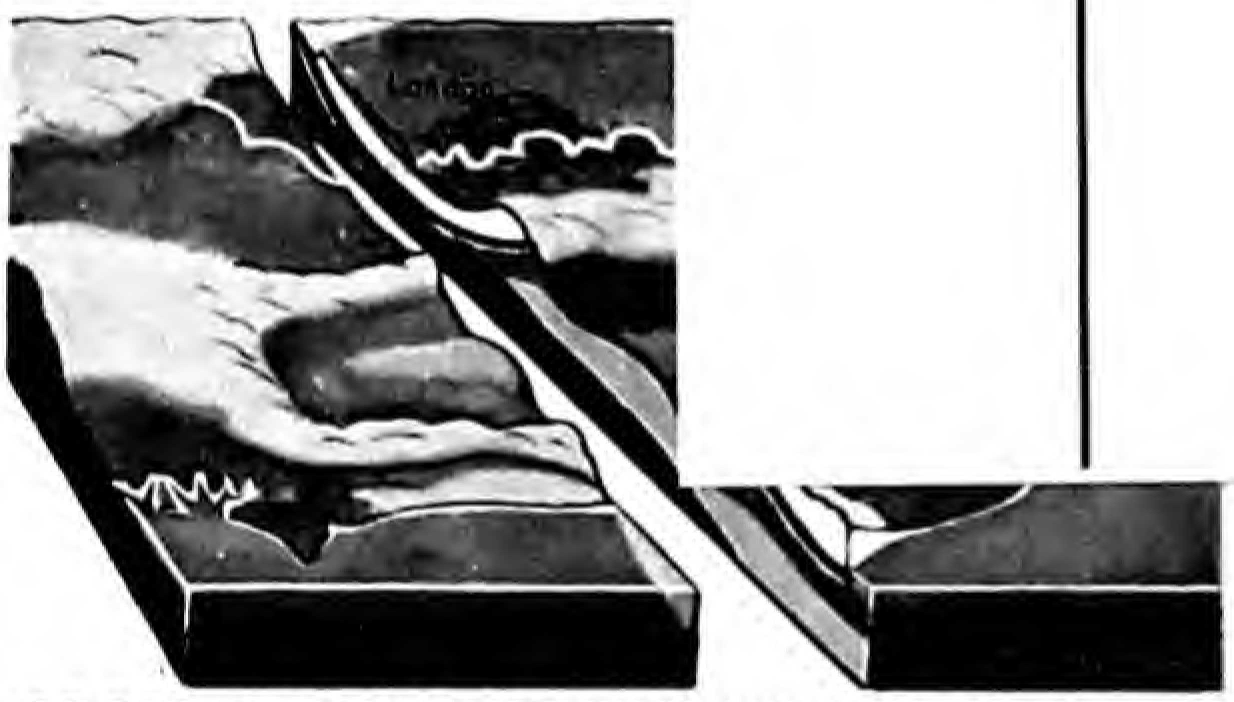
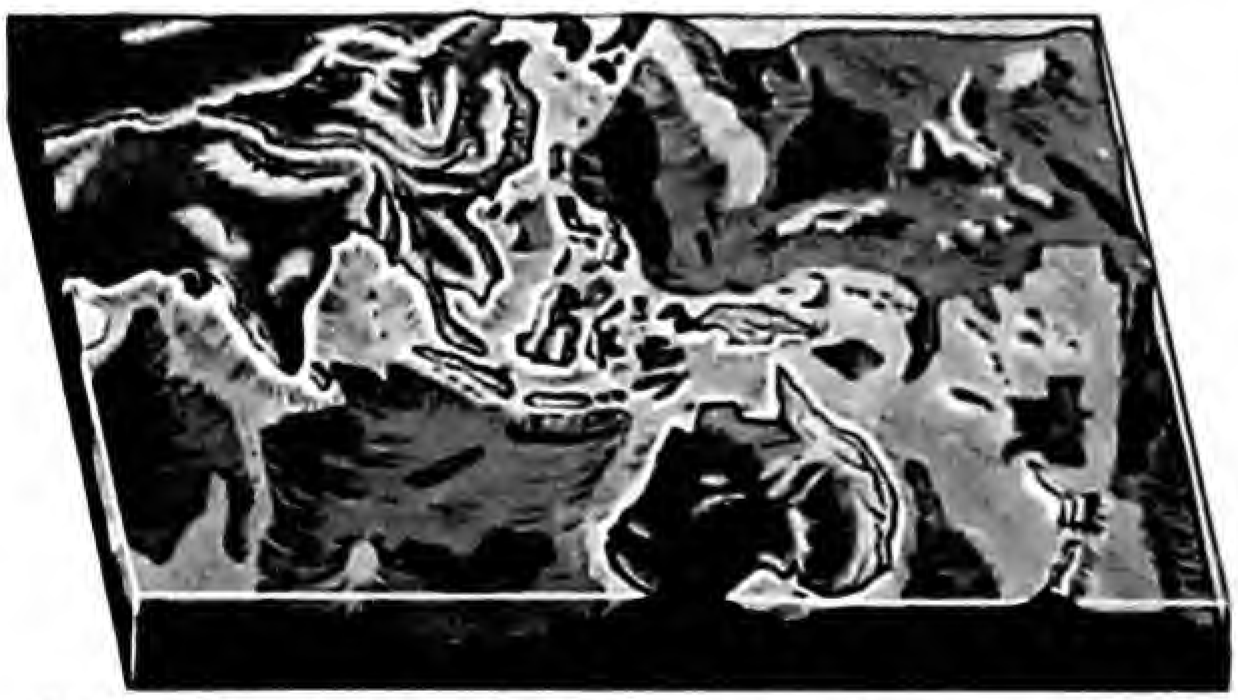
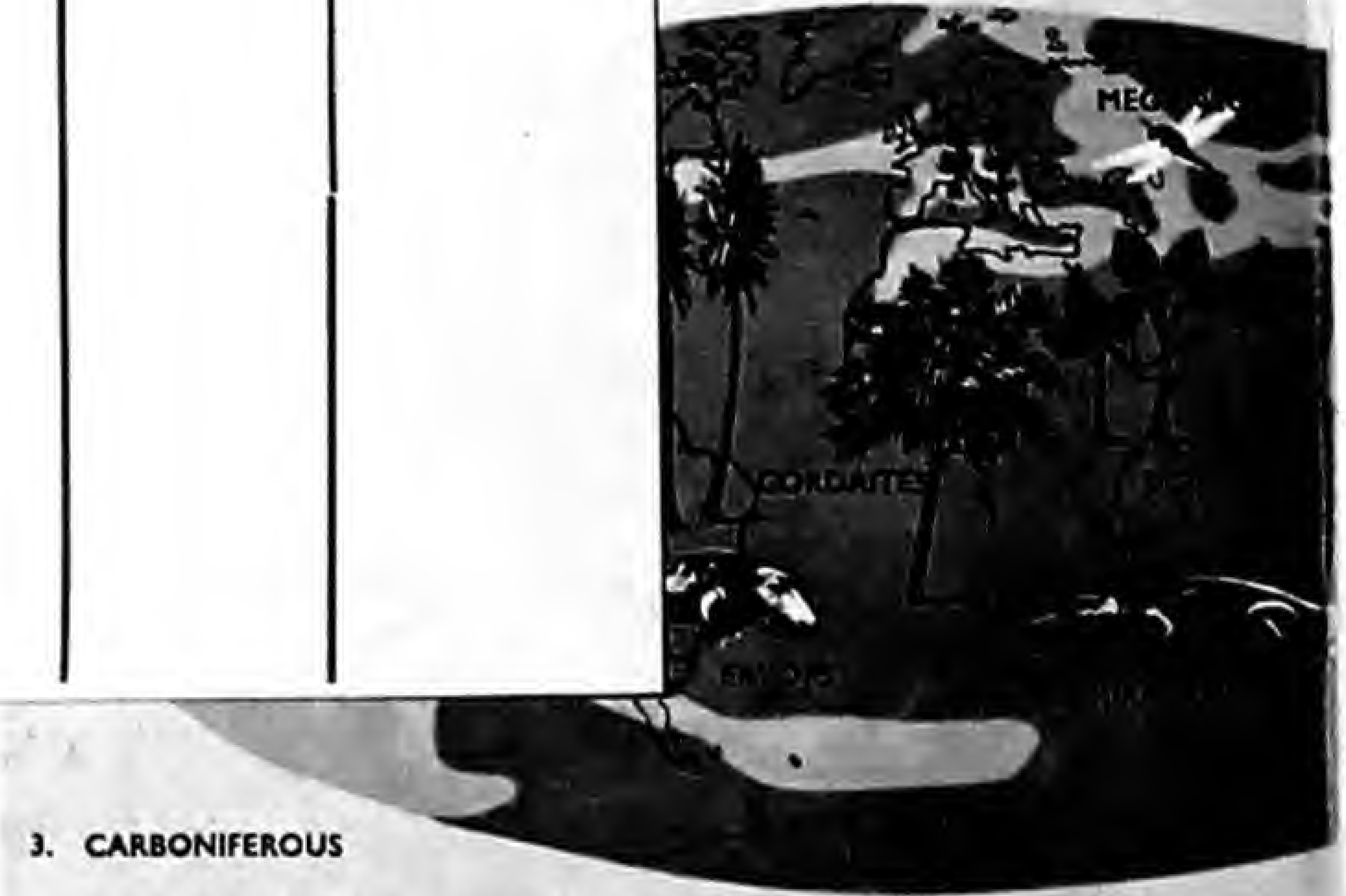


CROSS SECTION OF THE WEALD. Block model of the Weald to show that it is an ancient dome from which the weather has removed most of the chalky roof. *This has happened in the last 10 million years.*



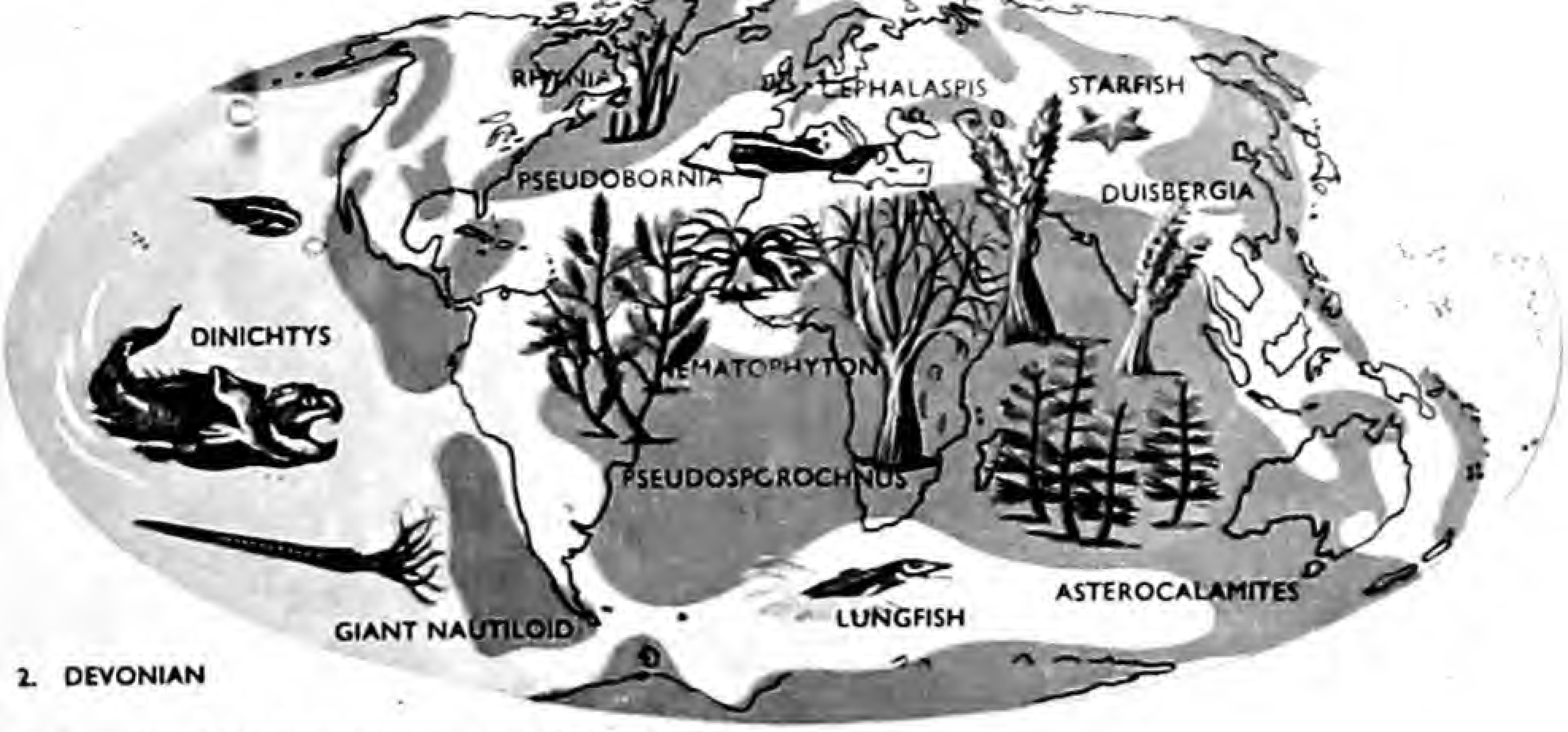
ONE OF THE MOST "RECENT" FOLDING AREAS has raised the earth's crust into mountain ranges and has given the sea its great depths. *About 15 million years ago.*

NE. LAND FREE
D ANIMALS



LAND PLANTS MORE VARIED. AMPHIBIANS VENTURE ON LAND, INSECTS FLY IN THE AIR,

THE END OF THE AGE OF REPTILES. CHALK (TETHYS) SEA COVERS LARGE PART OF EUROPE



2. DEVONIAN

AN AGE OF FISHES. SOME PLANTS NOW GROWING ON THE LAND

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6. MIOCENE

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Made and Printed in Great Britain b